POPULAR SCIENCE BOOKLET SERIES

AIR AND WATER

Author: Zhang Xueming
Translator: Xiao Tungying

CHINA SCIENCE AND TECHNOLOGY PRESS

FROM THE EDITOR

This booklet is intended as a popularizer of scientific knowledge of air and water which concern us so closely in all spheres of our daily life.

Using simple and common examples, this booklet described in general the constituents, the characteristics and the utilizations of air and water. An account of employing the scientific accomplishments in the utilization of air for human well-being was given. The practical measures for eliminating air pollution and maintaining clean water were introduced, too.

Throughout the booklet the author has endeavoured to relate his explanations with scientific observations and findings so as to help the reader get a better understanding of the ideas presented in the booklet.

Written in simple and clear terms with vivid illustrations, the booklet is suitable for readers of junior middle school training.

AIR AND WATER is one of the "Popular Science Booklet Series" that consists of the following twelve booklets: Mechanism, Sound, Heat, Electricity, Air and Water, Light, Astronomy, The Earth's Crust, Meteorology, Animals, Plants, and Physio-Hygiene.

Popular Science Booklet Series

AIR AND WATER

Author: Zhang Xueming

Translator: Xiao Tongying

China Science and Technology Press

First Edition 1985

Published by CHINA SCIENCE AND TECHNOLOGY PRESS
32 Baishiqiao Road, Beijing, China
Printed by THE FOREIGN LANGUAGES PRINTING HOUSE
19 West Chegongzhuang Road, Beijing, China
Distributed by the China International Book Trading Corporation (GUOJI SHUDIAN)
P.O. Box 399, Beijing, China
Printed in the People's Republic of China

CONTENTS

CHAPTER I

AIR SURROUNDING US

On this world where we live, everywhere is imbued with matters. The lofty mountains, roaring oceans, air surrounding the earth, coal and petroleum buried under the earth etc. are all those not matters? It is quite clear that the world is made up with matters. Where there is no matter, there is no world. In this matter world of all forms surrounding us, air is our closest friend.

Air — Our Closest Friend

Air is always together with us from morning till night. Without air, life will cease, iron ore will not be able to be processed into iron and steel, nitrogenous fertilizer will lose its resource, aircraft will not be able to rise into the blue sky as well. Air can be called as our closest friend. It provides us for breathing, heating, supplies us raw materials and helps us in transportation.

Although air is so close to us, we often didn't set with this friend in mind. For instance, when you see a bottle full of air, you always say: "It's an empty bottle with nothing in-

side." But when you drop it into water, you will find bubbles coming out. It solemnly declared that the bottle is imbued with air (Fig. 1).

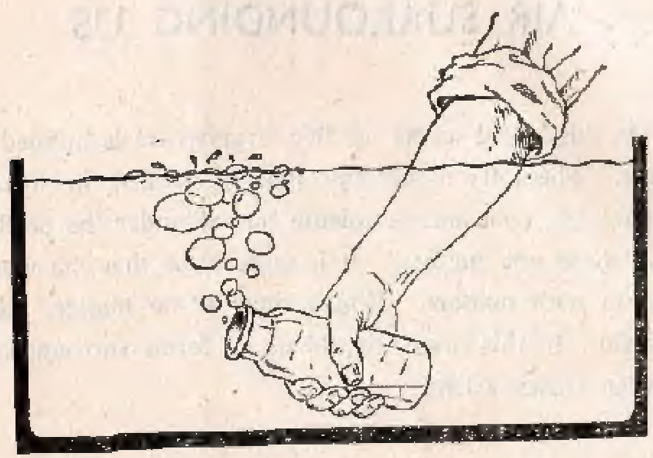

Fig. 1 Empty bottle, not vacant

Why didn't people set with air in mind? People should not be blamed for not showing ties of friendship. This is because on one hand air is a kind of gas with no color, no flavor, no definite shape or form. It cannot be seen, neither be smelled or touched, so it is not as attractive as things with color, flavor, as well as shape. On the other hand, the extent of air exists wider than any other matter. Air exists everywhere, at any time. So, it is unnecessary for people to stress its existence.

Although people turn a blind eye to air, it is really empty but not vacant. Experiments illustrated that normally, air with a volume of 1 litre, its mass is around 1.29 gram. Mass per unit volume is called matter density. The density of air = 1.29 g/l. Do not be little this figure, through calculation you will find air of 1 cubic meter weighs 1.29 kg; air in a normal classroom will be several hundred kilograms; air in a big hall can attain dozens of tons. Some one even had a calculation of air surrounding the earth, and achieved an astonishing figure: 5,000,000,000,000,000 tons.

In comparison of the density of air with other gases, it was found that air is 14 times heavier than the lightest gas — hydrogen, a bit heavier than nitrogen, and lighter than oxygen (Fig. 2).

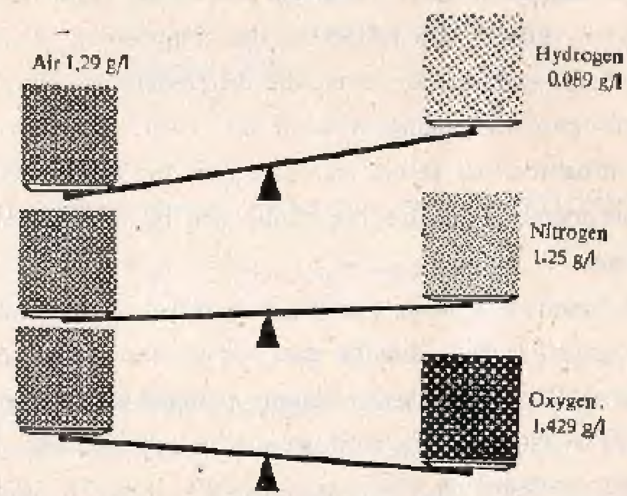

Fig. 2 The comparison of air density with other gases

Normally, although air is a kind of gas, it differs with hydrogen (H_2), nitrogen (N_2), oxygen (O_2). Air is not a kind of pure gas, but a mixture consisting of many kinds of gases. Therefore air is of a big family with quite a lot of members.

Members in the Big Air Family

How many members are there in the air's family? Strickly speaking, it is really quite difficult to make clear all the members. This is not only air consists of too many members, but also there are several visitors going back and forth. Fresh air in rural areas differs with polluted air in urban districts; so does the air in heavy polluted industrial districts with slightly polluted inhabitant areas; waste gas discharged from iron and steel plants differs with refineries, the composition of air are not quite the same either; even the differences of season, climate influence the composition of air. But, the abovementioned influences are rather small for this big air family. So the basic members of this big family can be maintained and unchanged.

Air mainly consists of nitrogen and oxygen, a small amount of rare gases, carbon dioxide gas, vapor, and other constituents as well. According to volume percentage, nitrogen occupies 78%, oxygen 21%, rare gas, carbon dioxide gas, vapor and other constituents totally occupies 1% (Fig. 3). Calculation according to weight, nitrogen covers 75.5%, oxygen 23%,

other 1.5%. Normally when talking about the constituent of air, it means the volume percentage. This is because of the principle for gases. Any gas with the same volume has the same amount of molecules under the same external conditions

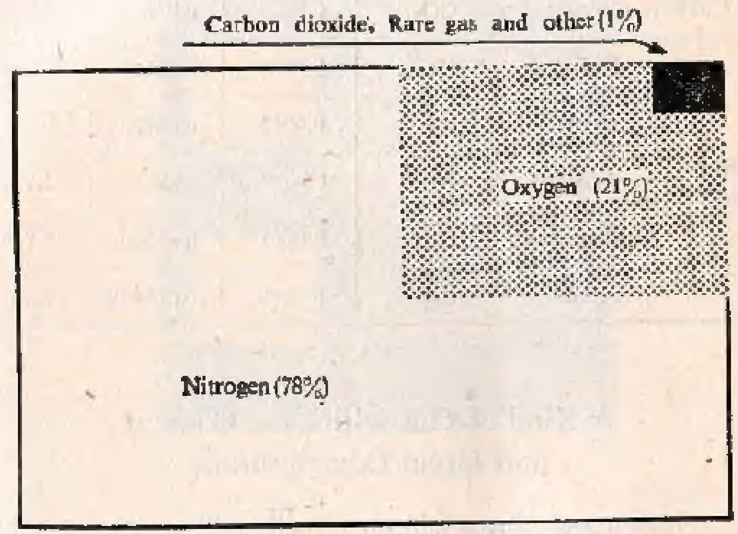

Fig. 3 The composition of air

(temperature, pressure). Oxygen covers 21% of the total air volume, that means oxygen molecules covers 21% of the total molecules in air, i.e. among 100 molecules there are 21 oxygen molecules.

The Percentage Content and Density of the Main Constituents in Air

Constituents		Chemical formula	Volume (%)	Weight (%)	Density (g/l)
Nitrogen		N_2	78.03	75.51	1.25
Oxygen		O_2	20.93	23.15	1.43
Carbon dioxide gas		CO_2	0.03	0.046	1.965
Rare gases	Helium	He	0.0005	0.00007	0.178
	Neon	Ne	0.0015	0.00125	0.9
	Argon	Ar	0.93	1.28	1.781
	Krypton	Kr	0.0001	0.00029	3.708
	Xenon	Xe	0.00001	0.000036	5.581

A Kind of Gas with Less Content and Great Contributions

Oxygen and nitrogen in air are all well known gases, but rare gases are not so popular. But for the latter, it has quite a lot of usages, even if they are not so reputed and rare as well. Before introducing oxygen and nitrogen, let's have a general view of rare gases.

At night when you take a walk in the downtown area, you will surely be attracted by the multicoloured neon lights (Fig. 4). Different kinds of rare gases are filled in these thin glass tubes: neon gives out a red light; argon blue, helium light

Fig. 4 Neon lights

red; a mixture of many kinds of rare gases can give out other colors.

Have you ever seen a hall or even a public square lighted with only one lamp? Xenon lamp has this ability. This kind of lamp gives out very strong white light and is called "small sun."

Perhaps you have also heard about hydrogen filled balloons? Hydrogen is far lighter than air. When a balloon is filled

with hydrogen, it can slowly rise in the air (Fig. 5). But hydrogen is also a bad tempered gas, combustible and explosive. Special care should be taken in using, otherwise explosion might happen. Rare gases do not have the abovementioned disadvantages. They are stable and will not easily have chemical reactions with other matters. So, they are usually called inert gas. Helium's density is the smallest among rare gases and besides hydrogen it is the lightest gas. If a balloon is filled with helium, it can also rise in the air like a hydrogen balloon. Helium is incombustible, unexplosive and safe. So

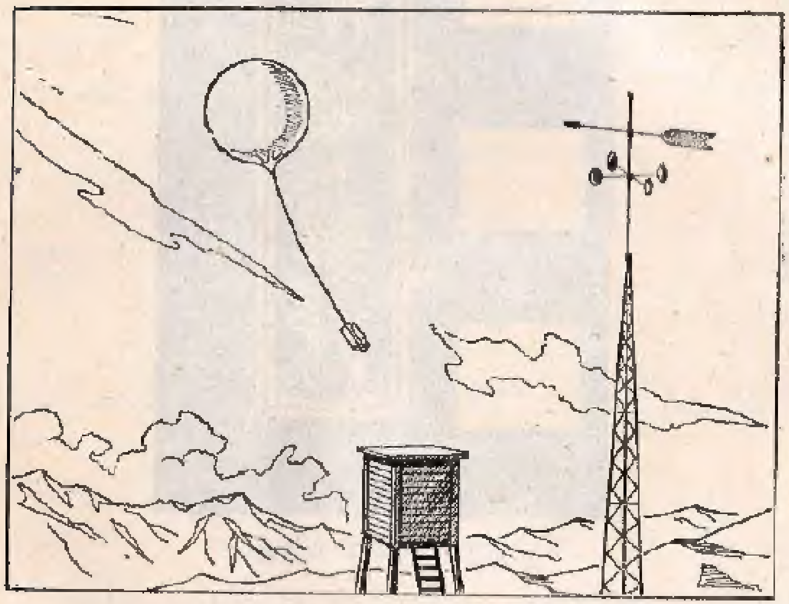

Fig. 5 Balloons rise slowly

helium as well as hydrogen, helium mixture are usually used for filling balloons.

Quite a number of aluminium products have been used in your daily life. Lunch box, kettle, steamer etc. can be made of aluminium. Aircraft as well cannot be made without aluminium. Aluminium is well received for its lightness and stainless. But difficult to weld is its biggest shortcoming. Why? This is because aluminium (Al) is an active metal in chemical properties. It is very easy to oxidize in air and form alumina (Al_2O_3). Welding can be smoothly carried out if rare gas is used as protecting atmosphere while aluminium is welded. This is because in such cases, aluminium is separated from air, so it cannot be transformed to alumina. Therefore, argon (Ar) is normally used as a protecting atmosphere in welding active metals such as aluminium, magnesium etc. Using rare gases as protecting atmosphere is not limit to welding. It plays an important role during the extraction of active metals. The extraction of titanium — an up and coming youngster in the metals field is an example. Titanium is a kind of metal with low density, high strength, heat and corrosion resistance, as well as abundant reserves. Many of its good properties surpassed aluminium and steel. It is a very good material for making supersonic aircraft, spaceship. It is renowned for "space metal". This metal was discovered in ore by scientist about 200 years ago. However, large quantities of production and application was a matter in the past thirty years. The reason is the chemical properties of titanium is very active under high temperature. Titanium metal easily reacts with oxygen, nitrogen, carbon etc., so it is very difficult to extract

pure titanium. Process currently used in extracting titanium metal is smelting under high temperature with rare gas as protecting atmosphere.

Besides, rare gases has quite a lot of important applications, such as medical treatment and health, electronic industry, atomic energy as well as cryogenics or vacuum technology. There are also other applications which we will not introduce here.

The total amount of rare gas in air covers less than 1%, it's really quite a small amount. But it doesn't means that in all cases rare gas is a "rare visitor" in nature. It was found in the past few years that there is a helium zone at the altitute between 760 km to 2400 km from the earth's surface. There is just a helium's world.

After we have had a preliminary idea of the properties of rare gases and their applications, now, let's see what are the important usages of oxygen and nitrogen, the chief members of the air's family in our daily life and production.

CHAPTER II
THE COMBUSTION OF MATTER IN AIR

Combustion is a common phenomenon in life. It was told by historians that combustion was already very popular as early as billions of years ago (Fig. 6). People learned to make

Fig. 6 The utilization of fire by mankind in the early days

ceramics, refine metals thus promoting the progress of social production (Fig. 7).

Nevertheless, in a very long historical period of time, people only knew how to use combustion, but didn't know the reason of it. It was not until the end of the 18th century, that a French chemist called Lavasy who advanced the combustion theory, revealed the unsolved mystery of combustion.

Fig. 7 The usage of fire for metal making by ancient Egyptians

How Did Lavasy Revealed the Mystery of Combustion

Before the founding of Lavasy's theory, scholars wrongly considered fire as an element and called it "combustion element". The flames produced while burning matters were explained as the emission of combustion element. If this was correct, the residues after combustion should be lighter than the original matter owing to the emission of "combustion element". However, the case was just the opposite. Weight of quite a few matters (such as metals) increases after combustion. Was there a way to solve this difficult problem? Many famous scientist could not give a reasonable reply at that time.

Lavasy decided to solve this problem through tests (Fig. 8). Since 1772, he spent five years to study combustion test and finally gained success. Lavasy's intelligence was that he not only paid attention to the weight increase of matters after combustion but also the weight decrease of air in the combustor. Results measured by balance showed that the weight increase of matter was just the right weight oxygen decreased in air. For instance, the two tin (Sn) combustion test results were:

	1st	*2nd*
Increased weight of Sn after combustion (unit)	3.12	10.00
Decreased weight of air after combustion (unit)	3.13	10.06

In 1777, Lavasy happily concluded his five year test results and put forward his combustion theory to Paris Academy of Science, thus dislosed the mystery of combustion to mankind. He pointed out, the reason why matters burn in air

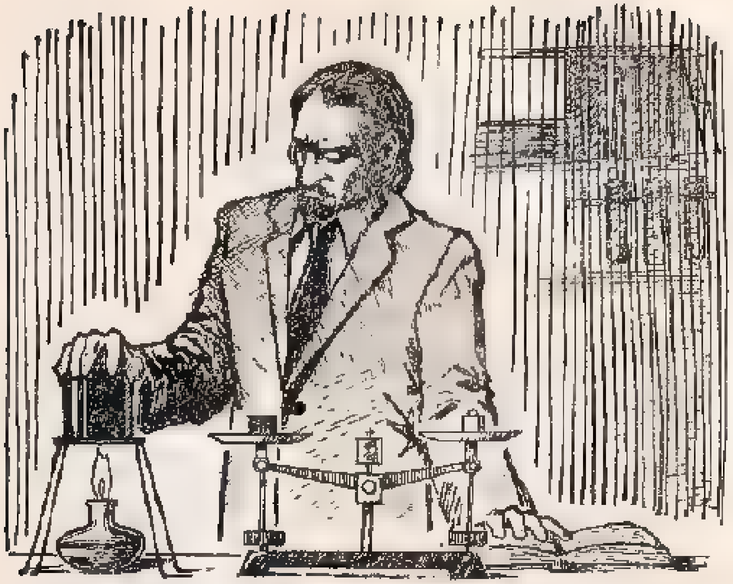

Fig. 8 Lavasy testing

is it reacts chemically with the oxygen in air; the increased weight of matter after combustion is the right decreased weight of oxygen in air; heat and light produced by matter during combustion is not the decomposition of "combustion element", but only a phenomenon happened during an acute chemical reaction.

Now, let's make a phosphorus combustion test to verify Lavasy's theory.

First, put a small piece of ordinary phosphorus into a wide mouth glass bottle, seal the mouth of the bottle and then heat the bottle with fire. You will find the ordinary phosphorus burns acutely with very bright flames and a certain

amount of smoke as well (Fig. 9). The smoke condenses on the wall of the bottle like a layer of white frost. This is phosphorus pentoxide which was formed by the combination of phosphorus and oxygen. The chemical reaction is as follow:

$$4P + 5O_2 \xrightarrow{\text{combustion}} 2P_2O_5$$

When the glass bottle is cooled, put it upside down in water and pull out the seal under the water surface. Then you will

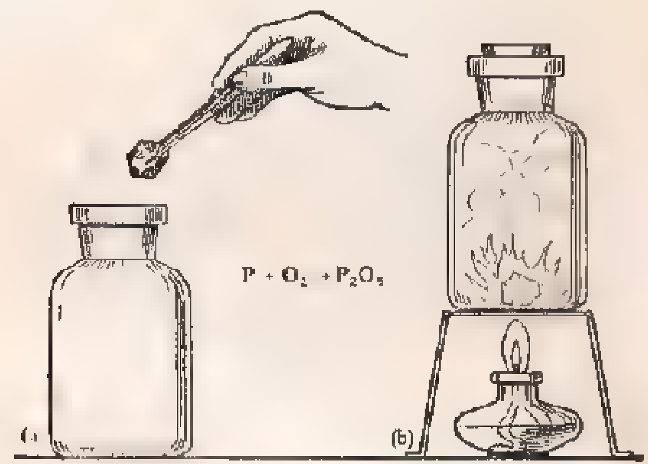

Fig. 9 Test of phosphorus combustion

see water flows into the bottle automatically until it occupies one fifth of the total volume of the bottle (Fig. 10). If a burning wooden stick is put into the remaining gas of the bottle, the flame will die out immediately. It illustrated that oxygen which occupies one fifth of the total volume of air combined totally with phosphorus to form phosphorus pento-

xide (the other four fifth of air is nitrogen etc. which did not burn and still remain in the bottle). The weight of phosphorus pentoxide is the sum of weights of the burned phosphorus and the oxygen in the bottle.

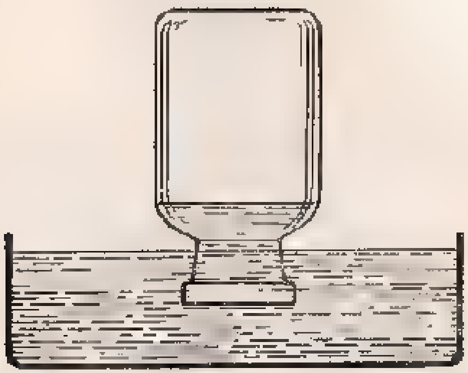

Fig. 10 Water that enters into the bottle occupies approximately 1/5 of the volume

It is obvious that the combustion of matter in air is really the fact that matter chemically reacts with oxygen. However, if amorphous phosphorus (like the kind on match-box) is put in the bottle instead of ordinary phosphorus, it will not burn, but only slightly baked, why?

This is because that the combustion of matter in air not only needs oxygen but also a certain temperature. This temperature is so-called burning-point or ignition point. Different matters have different ignition points. Phosphorus consists of amorphous phosphorus and ordinary phosphorus. The "two brothers" have different tempers. Ordinary phosphorus

is "short-tempered" and combustible as well. It burns at 40°C in air; amorphous phosphorus is not so "short-tempered", it has to be heated to 240°C to combust. So, for amorphous, slight roasting cannot make it burn. Burning reaction only takes place when continuously heated to ignition point (Fig. 11).

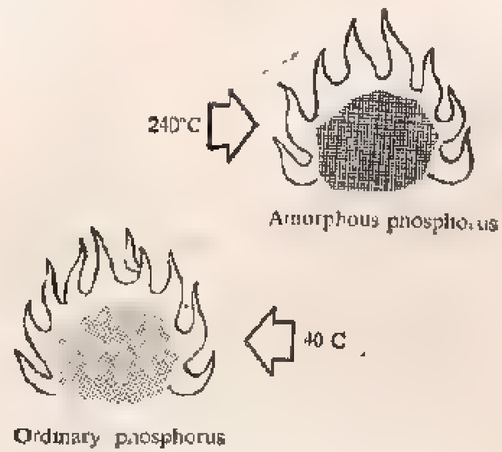

Fig. 11 Different ignition points for ordinary and amorphous phosphorus

Different matters have different ignition points. The ignition point of timber is a bit higher than amorphous phosphorus, over 250°C; the ignition point for anthracite is even higher, normally between 700 — 750°C. Because usually it can't reach this temperature, therefore, although contacting with air, timber or anthracite will not burn.

Ignition points for a certain amount of combustible matters are shown as follows:

The Ignition Points of Some Combustible Matters (°C)

Hay	about 172	Sulfur	260
Timber	250~330	Alcohol	558
Anthracite	700~750	Hydrogen	585
*Ordinary phosphorus	40	Acetylene	335
Amorphous phosphorus	240	Methane	537

Therefore, the combustion phenomenon of matters in air is an acute chemical reaction of matters with oxygen under a certain temperature with luminous and exothermic phenomena. The two necessary conditions for matters to combust in air are combustible matter contacts oxygen as well as temperature reaching the ignition point. Not a single one of these conditions can be dispensed with. Since the combustion of matter in air is only a chemical reaction with oxygen, then, are the combustion circumstances in air as well as in pure oxygen quite the same?

More Acute Combustion in Pure Oxygen

When a nearly died out match (with a small spark) is put into a bottle of oxygen, it will reburn immediately. If we put an iron wire heated to red in air into an oxygen bottle, it will

at once radiate beautiful and dazzling sparks, and looks like a small fire work (Fig. 12)

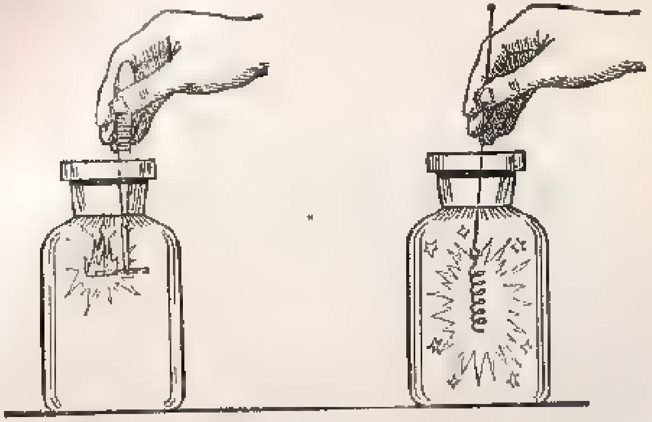

Fig. 12 More acute combustion of matter in pure oxygen

Facts told us that matter combusts even more acute in pure oxygen than in air. Why? This is because combustion is a chemical reaction between matter and oxygen. The more chances matter contacts with oxygen, the more it reacts, the more acute the combustion would be. According to the constituent of air, only one fifth of the total molecules in air can react with oxygen, the other four fifth remaining molecules are not oxygen molecules, they will depart from matter when contacting it without saying good bye. Things will be different in pure oxygen, oxygen molecule exists everywhere. It is obvious that in pure oxygen reaction is more acute due to more chances of contact of matters with oxygen.

For instance, the efficiency of top blown oxygen steelmaking process adopted in modern steel industry is much more

higher than the former air steelmaking process. The process for steelmaking is a process in reducing the carbon content as well as harmful impurities in pig iron by oxidation. The reaction for air steelmaking process used before is very slow, the temperature inside the furnace is rather low. The quality of product might be influenced also and quite an amount of heat is wasted owing to the large amount of nitrogen in air. The principle of oxygen top blown process adopted recently is that high pressure oxygen with a purity of over 99% is injected through a special injection lance which is plugged in from the top of the converter. Oxygen reacts directly with the blast furnace hot metal. The reaction is acute associated with a large amount of exothermicity. Decarbonization is rapid. A heat of steel can be produced within 20 minutes (Fig 13).

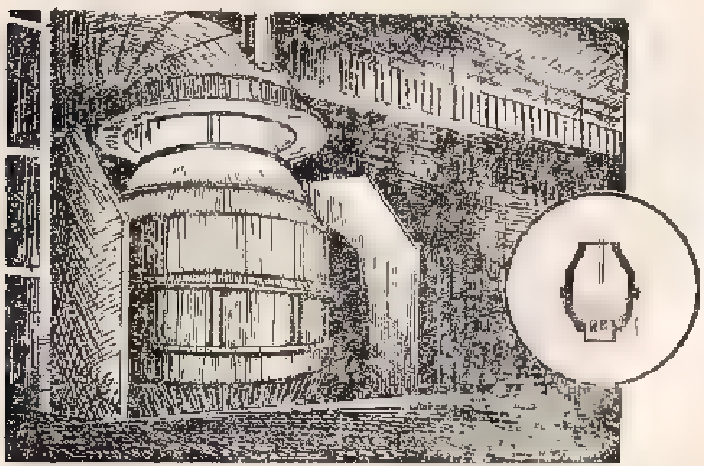

Fig. 13 Pure oxygen top blown furnace for steelmaking

Take flame welding as another example. We often see a flame welder holding a welding torch, whistling light blue flame gushes strongly from the nozzle of the torch. Even the strongest steel while contacting will sparkle (Fig. 14). What

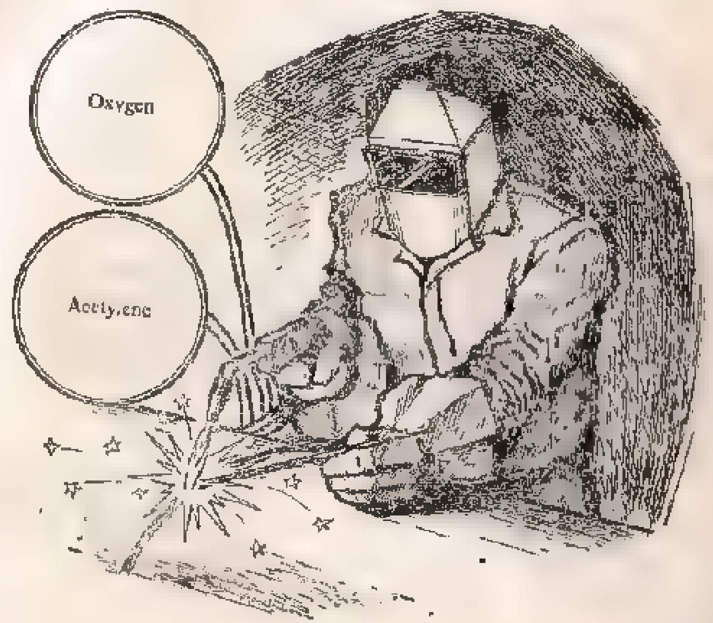

Fig. 14 A flame welder at work

kind of specific fuel is put in the torch to eject such high temperature flame? If you only study the conduct tubes of the torch, you will find there is really no specific fuel. Ethyne (C_2H_2), so-called acetylene, flows in one tube and oxygen in the other. Carbon dioxide and water are formed when acetylene

combusts in pure oxygen. A certain amount of heat is relieved simultaneously.

$$2C_2H_2 + 5O_2 \xrightarrow{\text{combustion}} 4CO_2 + 2H_2O + \text{heat}$$

Flowrates of these two gases must be adjusted properly in order to have full combustion. A high temperature of 3100°C can be produced. It is very easy to melt a common metal with this high temperature. Therefore, a high temperature flame which is obtained by the combustion of acetylene with oxygen called oxyacetylene flame is normally used in welding or cutting metals.

Furthermore, hydrogen which people are familiar of can obtain a high temperature flame — hydroxy flame around 3000°C. So, it is also a good hand in welding technology.

The combustion reaction of hydrogen and oxygen is as follow:

$$2H_2 + O_2 \xrightarrow{\text{combustion}} 2H_2O + \text{heat}$$

This will not pollute the air because the result of this reaction is water; furthermore, the reaction also emits a great deal of heat, one kilogram of hydrogen equals to 3 kilograms of gasoline, so, hydrogen is a new kind of fuel better accepted than gasoline.

Combustion and Energy

People usually refers fuel as the kind of combustible matter that can produce a great amount of thermal energy used for energy sources. Thermal energy by fuel during combustion can be directly used for heating to obtain high temperature,

it can also be transformed to optical energy, electrical energy as well as mechanical energy in application. In fact, not all of the combustibles can serve as energy. It depends on whether the resource is sufficient, usage convenient, thermal heat emission is able to meet the requirements. Timber has been the main energy used by mankind in the old days, and this has not changed until the beginning of this century. Later, it was shifted to petroleum and natural gas. Among the total energy demand, petroleum and natural gas covers 65%, coal 28%, others (hydropower, nuclear energy etc.) 7%. However, what worries us is petroleum, natural gas and coal as major sources of energy cannot last forever. This is because these reserves as minerals in nature are limited. Estimates made, according to the recent increasing rate of energy consumption, 87% of the petroleum reserve, 73% of natural gas might be depleted by 2000. This is the so-called energy crisis which people often talk about. The most important way for solving the crisis is to develop new energy besides energy conservation. In developing new energy, chemists happened to think of hydrogen simultaneously.

As a matter of fact, the combustion of hydrogen was discovered as early as several hundred years ago. Means for using hydrogen as fuel had been pointed out before, but it wasn't realized at all. The reason was because methods for the preparation and storage of hydrogen were not fully solved. The reserve of hydrogen in nature is rather small. It is necessary to find a cheap and easy way to prepare hydrogen in quantities in order to make it become a source of energy. Although hydrogen can be prepared by electrolytic water, but

the cost is high and not practical. At present, a way for using heat from nuclear reaction or solar energy to decompose water in preparing hydrogen is studied worldwide. Its chemical reaction is:

$$2H_2O \xrightarrow{\text{high temperature}} 2H_2 + O_2$$

Besides, as to the properties of hydrogen, under normal temperature and pressure it is in the form of gas and is combustible and explosive. So, it is necessary to solve the problem of storing. It is inconceivable that aircraft would carry a kind of gas fuel with minor quality and great volume up in the sky. People have found new ways to solve the storage problem: converting gaseous hydrogen to liquid by pressurized liquidation, thus greatly reducing hydrogen's volume, the other way is to make hydrogen react with metal, producing solid metal hydride, and hydrogen will emit by adding water or by heating when used. 1 kilogram of calcium hydride (CaH_2) can relieve about 1000 litres of hydrogen while contacting with water. A piece of titanium metal can absorb 1600 times hydrogen corresponding to its actual volume under normal temperature. This is quite similar to a "metal storage" for hydrogen.

Studies made in the last few years showed that there are a certain amount of alloy that can act as "metal storage" for hydrogen. Lanthanum-nickel alloy consisting of lanthanum and nickel has this ability. Test results showed one cubic meter of this alloy is capable of storing 88 kilograms of hydrogen, much more than the same amount of liquid hydrogen (71 kg/m^3). Hydrogen stored in a small 7 litres steel tank containing lanthanum-nickel alloy equals to a 40 litres high pressure hydrogen cylinder of 150 atmospheric pressure. Metal storage for hydrogen is not only easy to carry by aircraft, but also flexible enough to be used for automobiles. At present, some countries are developing metal hydride motors. It is estimated that aircraft by hydrogen power will be formally used within this century. During combusting the same weight of hydrogen and gasoline, the former will generate a far larger amount of power owing to its higher calorific capacity (28900 kcal/kg), therefore, aircraft by hydrogen power will be two times faster than the ordinary supersonic aircraft. Let's look forward to the prompt coming of the days of popularly using hydrogen energy.

Explosion, Combustion, Slow Oxidation

Special care should be taken in safety, when hydrogen is used for fuel. If a certain amount of hydrogen is mixed in air, a small spark can cause an explosion.

Chemical reaction for hydrogen explosive and combustion are just the same. Only the speed of reaction differs. Hydrogen is immediately ignited when it flows out the conduct tube, the contact of hydrogen with oxygen are limited to a certain small range around the nozzle of the conduct tube, regardless in air or in pure oxygen. Continuous relief of hydrogen will result in continuous combustion reaction. Although the reaction is acute, heat relieved is limited and can be diffused to the surrounding at any time. If hydrogen is mixed with air in a certain space i.e. when a certain amount of hydrogen is

mixed with air while firing, a great amount of hydrogen and oxygen molecules will be on the verge of breaking out and engaged in hand to hand fight, owing to the mutual contact of hydrogen and oxygen in a certain large area. A single spark might cause a comprehensive, rapid and acute reaction, thus contributing as an incident that touches off a war.

In a split of a second, innumerable hydrogen and oxygen molecules join the reaction and relieve a great amount of heat, which will be too late to diffuse gradually, thus causing a sudden volume expansion. This is called explosion.

When a certain amount of combustible gas such as hydrogen, acetylene, carbon oxide, methane, alcohol and gasoline steam etc. is mixed in air, it can cause explosion while encountering with fire.

Methane (CH_4) is normally mixed in the air of coal mines. If the content of methane in air reaches 5% by volume, explosion might happen when encounterng with fire. This is the so-called gas explosion. Gas explosion once happened in 1941 in a coal mine of Jilin Province. Over three hundred miners were killed by that accident. In 1942, over one thousand and five hundred miners were killed and wounded because of the gas explosion in Benxi mine, thus creating one of the biggest tragedy in world coal mining history.

Explosion is an oxidation reaction even more acute than combustion. But there still exist another kind of oxidation reacton which is slower than combustion. For instance, iron and steel get rusty, food turned putrid, fertilizer became thoroughly decomposed etc.

The rust of iron in air acutually is the process of changing iron to iron oxide. This means that iron carried out an oxidation reaction. This kind of chemical reaction proceeds quite slowly, with no luminous phenomenon. In chemistry, it is called slow oxidation.

In appearance, gas explosion, acetylene combustion, iron and steel rust seemed totally different, in essence they all belongs to oxidation reactions, which proceed with various, rapid, fast or slow speed. So it is clear that combustion are all oxidation reactions, but not all of the oxidation reactions do combust.

Is Combustion Possible Without Oxygen

Now let's do some further study on whether matter can combust without oxygen? Perhaps, you will answer definitely that combustion will surely be impossible without oxygen! Nevertheless, if you pay a visit to a chlorhydric acid plant, you will feel that your answer is not correct.

Chlorhydric acid is the solution of hydrogen chloride gas dissolving in water. Hydrogen chloride gas is exactly obtained by the combustion of hydrogen and chlorine (Cl_2).

If we carry out a test according to Fig. 15, put the hydrogen which is burning in air rapidly into a wide mouth bottle filled with yellow green colored chlorine. You will find hydrogen combusts continuously in chlorine and presents a pale white flame. Hydrogen chloride is obtained.

$$H_2 + Cl_2 \xrightarrow{\text{combustion}} 2HCl$$

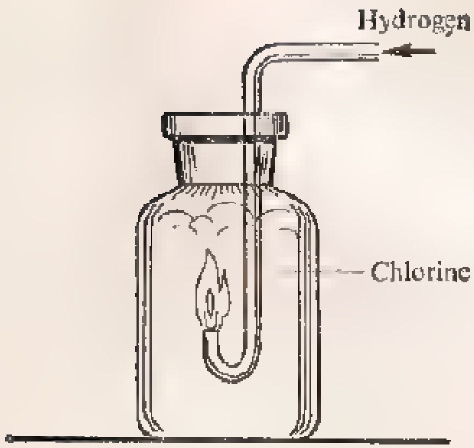

Fig. 15 The combustion of hydrogen in chlorine

It is thus obvious that matter is not absolutely incombustible without oxygen.

Certainly, combustion phenomenon like the combustion of hydrogen and chlorine is seldom seen. Oxygen usually takes part in common combustion. Therefore, for common combustion, the two necessary conditions for matter combustion are whether matter contacts with oxygen and whether the temperature reaches the ignition point. Measures and common principles for fire-extinguishment were adopted directed against these two conditions. Any disruption of one of those conditions will cease the combustion.

A Fire-Extinguishing Hero — Carbon Dioxide

The advantages of combustion are used both in production and daily life, but if we are careless, it might cause fire,

thus bringing a great loss for mankind. As for harmful combustion, vigorous fire extinguishing measures must be adopted immediately.

While mentioning about fire extinguishment, we cannot but think of carbon dioxide first. Because this is a hero who often appears and disappears in the case of a fire and who has obtained brilliant achievements. People often use froth extinguisher because carbon dioxide stands out in case of emergency to put out the fire. Why is carbon dioxide capable of extinguishment? First, this is because common matter doesn't combust in carbon dioxide. If we put a burning wooden stick in carbon dioxide, it would die out at once. Why is carbon dioxide often used for extinguishment among all other matters which do not substain combustion such as nitrogen? This is because it is heavier than air. Density of carbon dioxide is 1.5 times the density of air. Test in Fig. 16 shows when carbon dioxide is put into a vessel the lighted candle dies out gradually from the bottom to the top. This illustrated that carbon dioxide is heavier than air. For this reason, carbon dioxide gas sprayed from the extinguisher can cover the combustibles, enable it to separate from air. Thus, the purpose of fire extinguishment is realized. If a kind of gas which is capable of extinguishment but lighter than air is used, it would be easy to wind high above in air instead of covering the combustibles. In this case, the combustibles cannot be separated from air, combustion cannot be ceased.

There are many kinds of carbon dioxide fire-extinguishers, the most common one is froth extinguisher. At the corners of factories, warehouses or laboratories you may often see sev-

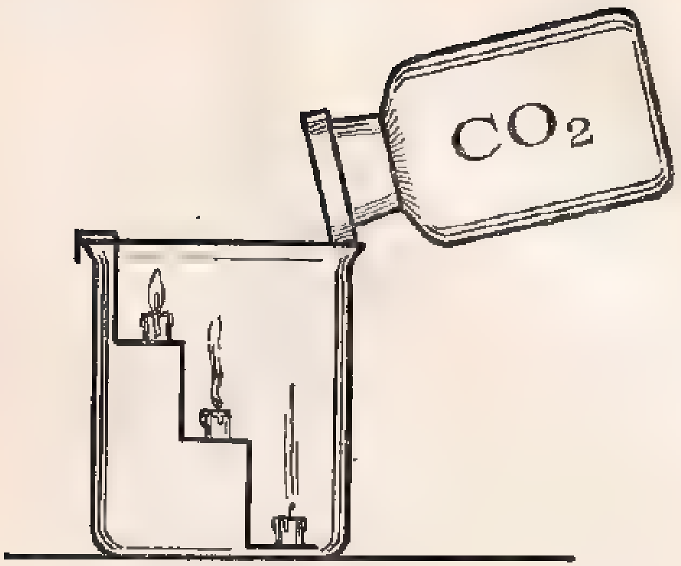

Fig. 16 CO_2 can extinguish and is heavier than air

eral red cylinders like thermos bottles. Those are the froth extinguishers (Fig. 17). Two kinds of solutions which are kept apart from each other are filled in those extinguishers instead of carbon dioxide. These are sodium bicarbonate ($NaHCO_3$) and aluminium sulphate [$Al_2(SO_4)_3$]. Extinguisher has to be put upside down when used (Fig. 18). Then, the two solutions in the cylinder mixed with each other and chemical reaction takes place. A great amount of carbon dioxide gas formed sprayed rapidly together with froth liquid. Owing to the froth agent mixed in solution, carbon dioxide froth sprayed can better cover the surface of the combustibles, thus playing a role in isolating air. This kind of extinguisher is ef-

Fig. 17 Froth extinguisher

Fig. 18 The application of froth extinguisher

fective, convenient and usually used for extinguishing fire caused by common matter or oil. Because liquid sprayed is able to conduct electricity, so power supply has to be shut off to avoid electric shock when electrical equipment is on fire.

There is another kind called carbon dioxide extinguisher. Compressed liquidized carbon dioxide is filled inside the cylinder. Turn on the switch when using, carbon dioxide can spray out. Since carbon dioxide do not conduct electricity, it is often used to extinguish fire caused by electrical equipment or chemicals.

The so called dry powder extinguisher (Fig. 19) consists of two parts, a quite small steel bottle and a larger cylinder Liquidized carbon dioxide is filled into the steel bottle while dry powder extinguishing agent (such as sodium bicarbonate) is filled in the cylinder. Turn on the switch of the steel bottle when in use, carbon dioxide will be compressed immediately into the cylinder. Owing to the great pressure of carbon

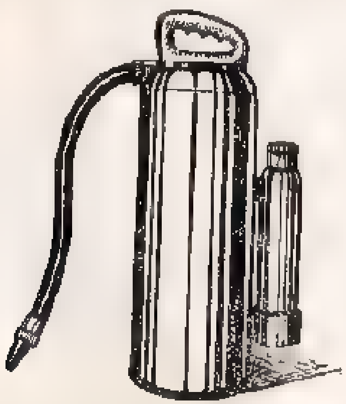

Fig. 19 Dry powder extinguisher

dioxide, dry powder can be brought along together with it and sprays rapidly from the nozzle. A great amount of carbon dioxide powder mist can extinguish fire quickly. This kind of extinguisher is suitable for extinguishing fire caused by oil, chemicals, electrical equipment. It fully displays the extinguishing ability of carbon dioxide.

Of course, carbon dioxide is not the only fire-extinguishing hero on the scene of a fire, water is another vital new force. Water for extinguishment has rich resources. A great amount of water sprayed on the combustibles can not only isolate air but also achieve remarkable temperature drop owing to heat absorption for the vaporization of water. Because oil is lighter than water, and can float on water to continuously contact with air, it cannot be used to put out a fire caused by oil (Fig. 20). Also because water can conduct electricity, it

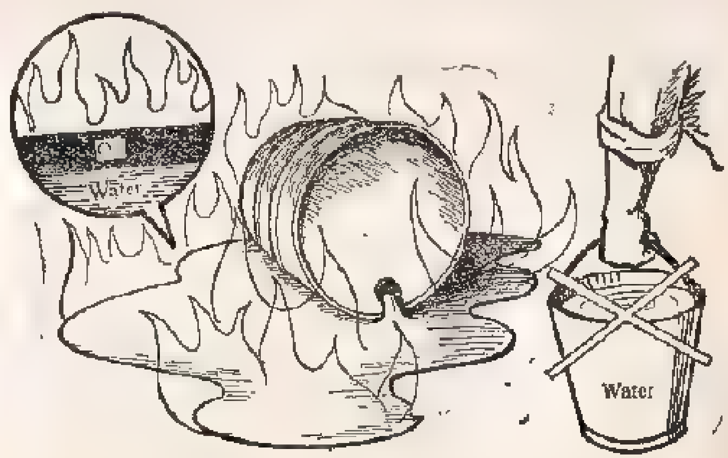

Fig. 20 Water cannot be used to extinguish fire caused by oil

cannot be used to put out a fire caused by electrical equipment too.

In short, there are various ways and implements for fire-extinguishment and treatment can be made according to different circumstances. In general, there are only two principles: first, combustibles should be isolated from air; second, temperature should be reduced to below the ignition point. In other words, try by any possible means to destroy the two conditions for matter combustion.

It is obvious the purpose of our extinguishment is rather clear. What we extinguish is the combustion which is harmful for the living and production of mankind. As to those profitable combustions rather than extinguishing, we feel its combustion is far not enough. Recently, because of the lack of combustibles such as petroleum, coal, energy crisis occurred in quite a number of countries worldwide. This shows, the combustion of matter in air is one of the important resources for mankind to obtain energy.

CHAPTER III

NO AIR, NO LIFE

Sufficient energy is not only necessary for mankind in their daily life and production, but also most important for the existence of life itself. Of course, this kind of energy doesn't come from heat relieved by the combustion of petroleum or coal, but comes from the oxidation of nutriments in the body. How can nutriments in the body oxidize and relieve heat? All this relies on breathing.

Any person from birth to death within a time period of several decades or even over a hundred years could not stop breathing air for even a short while. If there is no food, life could last for several days, but if there is no air, life would be over within several minutes. So breathing is most important for life.

What Is the Secret of Breathing

Energy is necessary for human body to conduct various physical activities and to keep a certain body temperature. Where does the energy comes from? This relies on the heat relieved while nutriments from food react with oxygen in the human body. Oxidation of nutriments such as oxidation of

carbohydrate, fat, protein belongs to slow oxidation. For instance, the oxidation of glucose ($C_6H_{12}O_6$)

$$C_6H_{12}O_6+6O_2 \longrightarrow 6CO_2+6H_2O+\text{heat}$$

Although the amount of heat relieved from carbohydrate, fat and protein differs, but it all belongs to reactions with oxygen and finally producing carbon dioxide and water. Oxygen required for those reactions is actually the oxygen inhaled by a person while breathing in air. It is obvious that the process of breathing is really the process of inhaling oxygen and exhaling carbon dioxide. It is also a process of utilizing the oxidation of nutriments to obtain heat.

Breathing is not only accomplished by lungs. In fact, it is the process of oxygen touring the human body. After oxygen is inhaled into the lungs it first enters into blood vessels through the membranes of pulmonary alveolus, blood in the vessels will then carry oxygen to the whole body and oxidation will occur. Carbon dioxide produced from the oxidation reaction will be absorbed by blood and exhaled through the lungs.

If you exhale gas into clear limewater through a tube, you will find the clear limewater becomes turbid (Fig. 21). The reason is carbon dioxide exhaled reacts with limewater (calcium hydroxide solution), and produces white calcium carbonate which does not solute in water.

$$CO_2+Ca(OH)_2 \longrightarrow CaCO_3\downarrow +H_2O$$

In chemistry, this test method is often used to determine the existence of carbon dioxide.

Fig. 21 Carbon dioxide makes clear limewater turbid

Normal content of carbon dioxide in air, according to volume is approximately 0.03%, but nevertheless, carbon dioxide content covers 4.5% of the total gas exhaled by an adult. Carbon dioxide exhaled by an adult per day is around 0.5 m^3

Test shows that through breathing, people cannot use up all the oxygen in the air, oxygen content still occupies 16.5% of the gas exhaled. If you put a burning wooden stick into the gas exhaled it will not die out immediately.

As for breathing, we usually say it is a process of inhaling oxygen and exhaling carbon dioxide, but in fact, in normal circumstance, a healthy person inhales air but not oxygen, and exhales not merely pure carbon dioxide but air

with the increase of a few percent of carbon dioxide and decrease of a few percent of oxygen (Fig. 22)

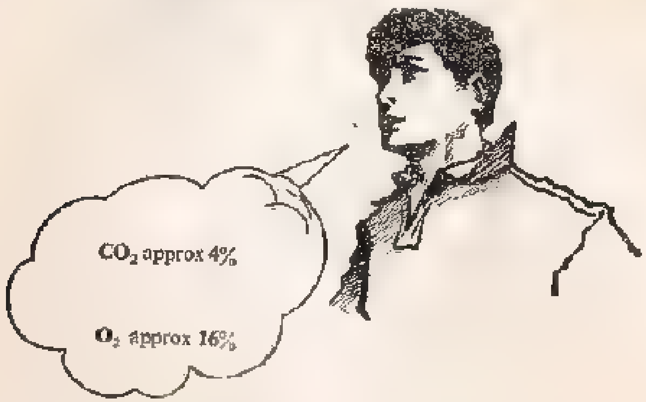

Fig. 22 Air exhaled

But, in special cases or for some patients, merely oxygen supplied by air is not sufficient, they need to breath in pure oxygen or an addition of pure oxygen would be necessary.

People Who Needs Pure Oxygen

Why do the pilots and mountaineers or even a strong young man find breathing difficult when they are at an altitude of 5 kilometers above sea level. Is it because that the percentage of oxygen in air lowers a lot merely at 5 kilometers above sea level? Of course, this is not the reason. Not merely 5 kilometers, even ten times of 5 kilometers, say at an altitude of 50 kilometers oxygen in air in terms of percentage still covers 21%. But percentage doesn't represent the actual amount of quantity. Investigation shows air weight per unit volume changes obviously at different altitudes. Air weight

is about 1.3 kg/m^3 near the sea level, but at an altitude of 5.5 km it drops to 0.6 kg/m^3, and only 4 g/m^3 at an altitude of 40 km (Fig. 23). Although the content of oxygen in terms of percentage shows no difference at the altitude of 40 km, the actual quantity, however, differs by 300 times. It is the earth

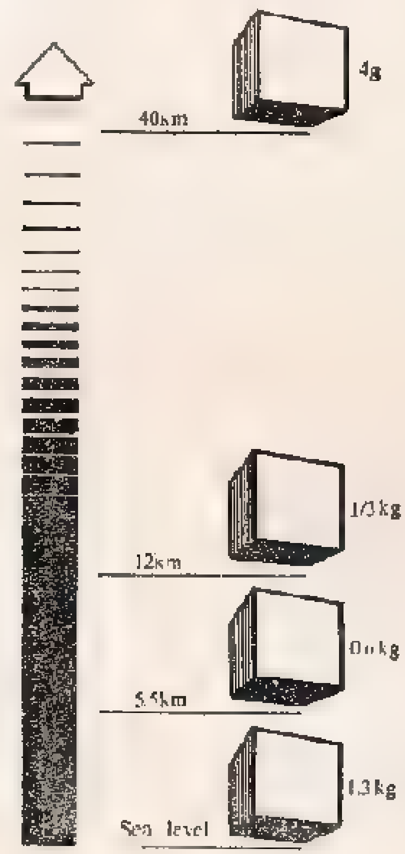

Fig. 23 Difference of weight of 1 m^3 of air at different altitudes

gravitation which causes this phenomenon i.e. the higher the altitude, the thinner the air. The nearer to the earth surface the more concentrated are the molecules. The further from the earth surface the thinner the molecules. At an altitude of 5 km from the earth surface inhaling once equals to inhaling less than half of its quality on earth surface. Owing to the big decrease of oxygen inhaled, breathing would certainly become difficult. Therefore, pilots and mountaineers have to carry oxygen bottles with them to compensate the less oxygen in thin air.

Divers working under water depends also on oxygen bottles for breathing. Pure oxygen is also required for patients in case of breathing difficulties (Fig. 24).

Not only mankind has the ability of breathing. All living beings in nature need breathing. All of them inhales

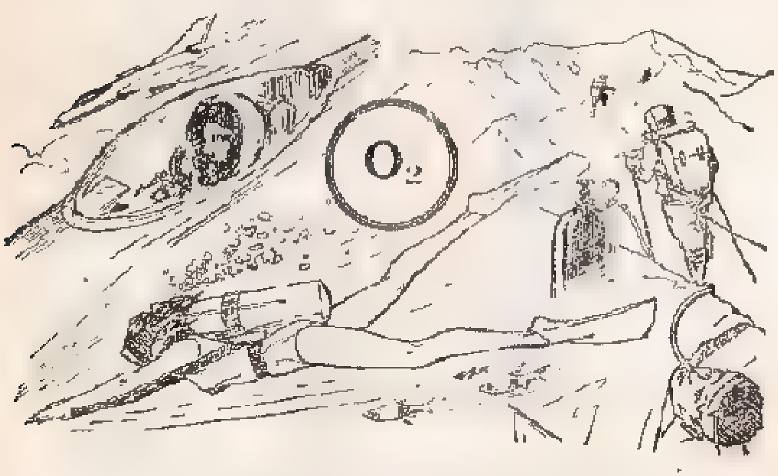

Fig. 24 People who need pure oxygen

oxygen and exhales carbon dioxide. But as to how to implement their ability, each of them has their own way. Mankind and many other animals breathe through their lungs; but earth worms depend on their epidermis; while fish in water use its gills to absorb the soluted oxygen.

Since all living beings have to breathe, will the total volume of oxygen in nature gradually decrease? Long ago, there was a scientist who worried about this. He believes the consumption of oxygen will be more and more along with the increase of world population and the development of industries. As the total amount of oxygen on earth is limited, after a period, say 500 years, oxygen will be depleted. Then, human beings will face destruction. How pessimistic is this estimation! Life didn't progress in accordance with the estimation of this scientist. Oxygen in nature didn't decrease at all.

Why Oxygen Didn't Decrease in Nature

About 200 years ago, test had been carried out by one who put a burning candle into a glass hood. The candle died out after a short time due to its consumption of oxygen. The candle will burn for a longer time if a green plant such as peppermint is placed in the same hood under the sun (Fig. 25). How can we explain this strange phenomenon? Why is the green plant under the sun so powerful?

Another interesting test was carried on by someone who soaked green leafs in water. After putting it under the sun, a

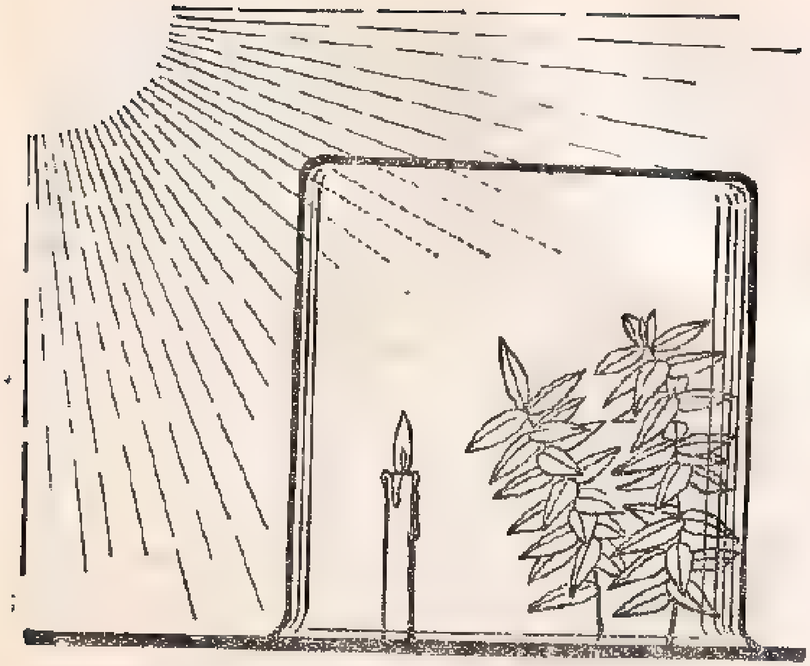

Fig. 25 Hood with peppermint inside can keep the candle burning

lot of bubbles emerged (Fig. 26). Collect the bubbles with a test tube and put some pieces of wood with fire sparks into it. It was found that the pieces of wood burned acutely. This exactly showed that the emerging bubbles was oxygen. When carbon dioxide was injected into the water, he was surprised to find out the more carbon oxide in water the more oxygen it generated.

Many research conducted by scientists showed that this phenomenon is the photosynthesis of plants. Plants absorb

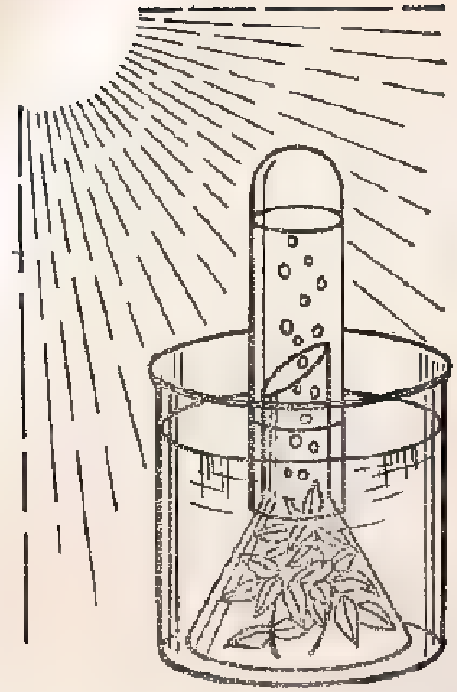

Fig. 26 Green leaves soaked in water will emerge bubbles

solar energy through chlorophyll, and promotes the reaction of carbon dioxide with water, thus forming glucose, starch etc., as well as relieving oxygen. This photosynthesis of green plants in the sun absorbing carbon dioxide and relieving oxygen is just opposite to breathing. Carbon dioxide from breathing can be absorbed by the photosynthesis; oxygen consumed by

breathing can then be compensated by photosynthesis (Fig. 27).

$$\text{Glucose} + \text{Oxygen} \underset{\text{photosynthesis}}{\overset{\text{breathing}}{\rightleftarrows}} \text{Carbon dioxide} + \text{Water}$$

The existence of breathing and photosynthesis in nature is the basic reason for the unchanged amount of oxygen in air. Besides, the combustion of fuels in production and daily life consumes oxygen and emits carbon dioxide, but the weathering of rock in nature again needs to consume carbon dioxide. There are various ways for consumption and compensation, but generally, consumption and compensation are under a stage of balance. Therefore, exhaustion of oxygen and human beings facing destruction will never happen.

Fig. 27 Circulation of oxygen in nature

Nevertheless, if we try to precisely determine the amount of oxygen or carbon dioxide in air, we will find its content changes slightly year by year. According to reports concerned, the content of carbon dioxide in air increases progressively year after year. During the past century it increased approximately by 13%. This is mainly because the consumption of fossil fuel shows a remarkable increase along with the development of industry. Owing to the small amount of carbon dioxide in air (0.03%), though carbon dioxide increased 13% within a century, its influence is extremely small to the whole air structure

The appropriate increase of carbon dioxide in air benefits the photosynthesis of plants and promotes the increase of agricultural output. There is another kind of gas making great contributions in agriculture. This is nitrogen covering a large portion in air.

CHAPTER IV

RAW MATERIAL BASE FOR FERTILIZER PLANTS

Nitrogen covers 4/5 of the total volume in air. Although this number is less than one. You will be surprised of its actual weight. Calculations made according to the earth surface area, you will find 7.5 million metric tons of nitrogen per square kilometre. Nitrogen surrounding earth is about 4,000,000,000,000 tons. This is an inexhaustible natural resource and the raw material base for fertilizer plants.

An Indipensable Element

When nitrogen was first being found 200 years ago, a test was carried out showing that a living mouse in nitrogen died quickly owing to the lack of oxygen (Fig. 28). Therefore, nitrogen obtained a remark of not being able to maintain life.

In fact, this remark isn't fair. It is true that nitrogen cannot help breathing, but the nitrogen element which exists in certain compounds are just indispensable in life. Nitrogen content in protein, so-called the base of life, is about 17%. An

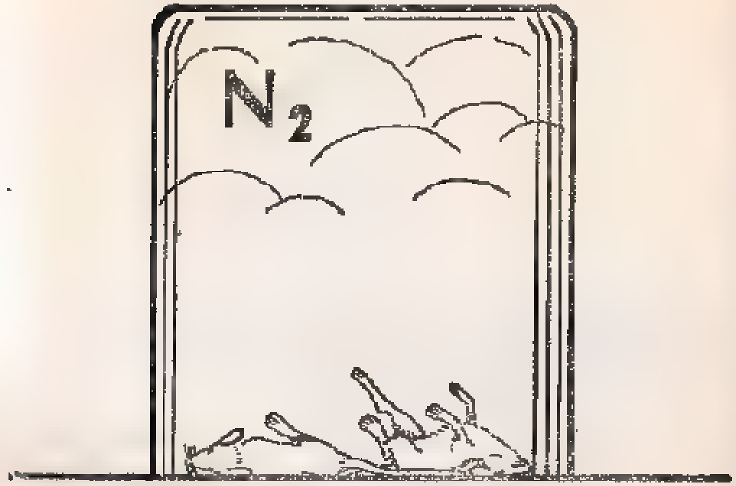

Fig. 28 Test on mouse

adult needs to extract about 90 grams of protein from food per day. Sufficient nitrogen is necessary also to make plants grow. Without nitrogen, the chlorophyll content will decrease, leaves will turn yellow, formation of protein will be restricted, crops will be small and weak, output will certainly be reduced. So, nitrogen ranks the first among the three main elements (nitrogen, phosphorous and potassium) for making plants grow (Fig 29).

Since all animals and plants need nitrogen, then, why don't they absorb it directly from air, instead of sending to the fertilizer plants for the production of fertilizer? This is because animals and plants absorb nutriments through certain organs in certain ways. For instance, a human body

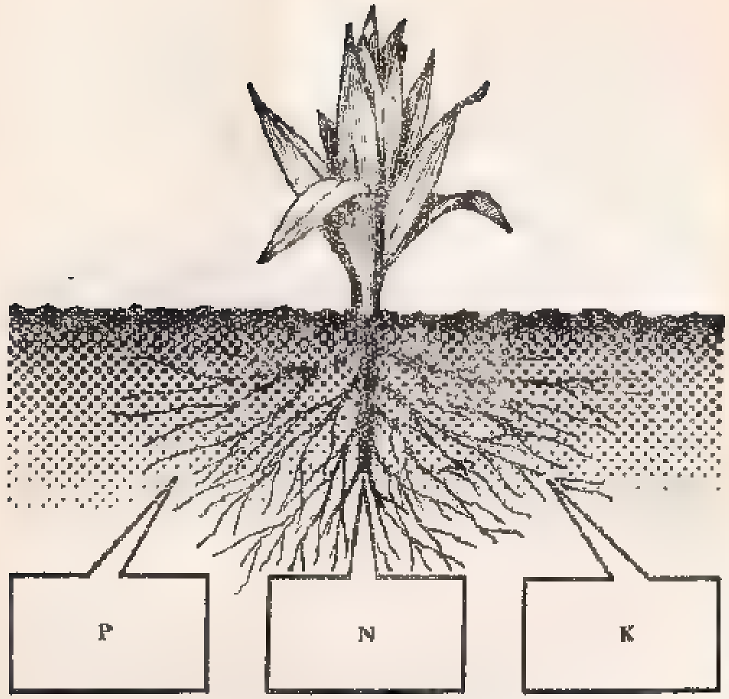

Fig. 29 Three main elements for making plants grow

requires calcium, which can be extracted only from food or supplemented by pharmaceuticals, but cannot be substituted by swallowing calcium metal or eating a piece of calcium content limestone every day. Plants cannot absorb nitrogen directly, they can only assimilate nitrogen compounds in soil solution. Therefore, the only way to provide nitrogen required by plants is to produce nitrogen fertilizer from nitrogen and then apply it to soil.

How Can Nitrogen Be Processed Into Nitrogen Fertilizer

It is not easy to process free nitrogen in air into nitrogen fertilizer. Before this century, quite a number of scientists and engineers racked their brains in research, but even then, they were not able to find a feasible way for solving this problem. It was not before sixty years ago, a German chemist by the name of Habor successfully carried out a reaction of nitrogen with hydrogen which formed ammonia (NH_3), thus developing the production of nitrogen fertilizer. This is so-called synthetic ammonia industry which occupies an important position in chemical production.

The chemical reaction of synthetic ammonia with nitrogen and hydrogen equals:

$$N_2+3H_2 \longrightarrow 2NH_3$$

Ammonia solutes easily in water and obtains liquid ammonia which is a kind of liquid ammonia fertilizer commonly used and welcomed by customers. Furthermore, ammonium sulphate fertilizer commonly used in rural area is a kind of white solid of ammonium sulphate [$(NH_4)_2SO_4$] resulted by the reaction of ammonia with sulphuric acid (H_2SO_4); the ammonium hydrogen carbonate in common use is also called "gas fertilizer". It is a kind of white solid of ammonium hydrogen carbonate (NH_4HCO_3) produced by the reaction of ammonia with carbon dioxide and water. Urea [$CO(NH_2)_2$], well known for its high nitrogen content is produced also by the reaction of ammonia and carbon dioxide under certain pressure and temperature. Though ammonia smells bad, it is very much

apprectated in producing chemical fertilizer. Besides, hydrogen can also be used to produce nitric acid, explosives, liquid ammonia is used as refrigerant (Fig. 30).

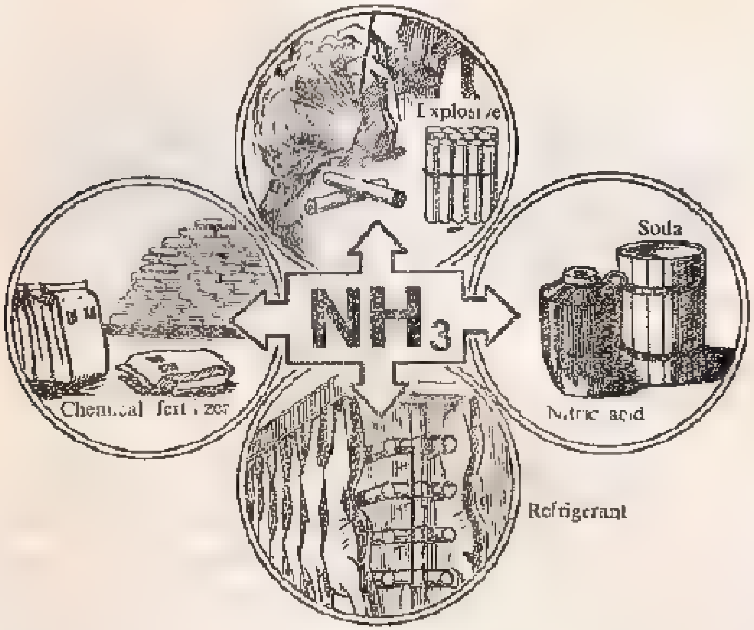

Fig. 30 Utilization of synthetic ammonia

The chemical reaction of nitrogen and hydrogen producing synthetic ammonia cannot be easily accomplished. High pressure, high temperature and also catalysts have to be adopted to speed up the chemical reaction. This restricted the development of production. Is there a way to process nitrogen into ammonia under normal temperature and pressure? This is a task which scientists are mostly interested in. People find

that, in nature there are varieties of nitrogen fixation bacteria which are able to process nitrogen in air into ammonia under normal temperature and pressure, this is called biological nitrogen fixation. It is estimated that nitrogen for biological nitrogen fixation on earth annually amounts to 175 million tons which is over 4 times of the industrial production. A great cause can even be done by a small bacteria, that is the reason why scientists take nitrogen fixation bacteria as a teacher. Nevertheless, this teacher can neither speak nor write. It cannot teach positively, but can wait for people to imitate and study. People made great progress in this study. Best wishes to the scientists for their success in the imitation of biological nitrogen fixation.

CHAPTER V

THE FLYING OF AIRCRAFTS IN AIR

The imitation of biology didn't start from nitrogen fixation in science and technology. In history, many successes obtained started from the imitation of biology. Aircraft is one of the examples.

From Flying Birds to Aircraft

Everyone has their own childhood full of fantasies. At that time, when you saw a bird flying freely in the sky, perhaps you had been imagining how interest it would be if one day someone might grow a pair of wings to fly easily in the blue sky. Not only children, even the grown up authors and poets symbolize petrel, eagle as the image of liberty. In the early days our ancestors who loved science and technology made instruments imitating the flying birds.

As early as two thousand years ago, a famous craftsman in China called Lu Ban had used bamboo to manufacture wooden bird which can fly. Later on, during Wang Mang period of West Han dynasty (7 —23 A.D.), someone tied feathers of big

birds to their body as wings and flew for several hundred steps. This could be known as the first try of mankind for flying.

In 1783 two French brothers invented hot air balloons which ascended to a thousand meters. This is because hot air is lighter than cold air and possesses buoyancy in air. But when the air is cooled, air density inside and outside the balloon became the same, thus causing it to descend.

Later an interest event happened in Paris of France. One day, Professor Shar made a big balloon. After filling with a kind of gas, it flew automatically up into the sky. Some time later, the balloon landed near Paris (Fig. 31). People there were greatly frightened by this big monster dropped from heaven. They prayed for God's blessing but nobody dared to go near it. Finally, a brave young man shot at this monster with a pis-

Fig. 31 The balloon landing near Paris

tol. The gas was let out. This was the first balloon filled with hydrogen.

After the appearance of balloon, airship (Fig. 32) which can be used as a kind of flying instrument was made through repeatedly renovations. This airship equipped with engine, propeller, rudder was able to lift vertically, fly at a same level and stop in the air by manual operation. But its speed was low and the airship was easy to have accidents owing to gas leakage and explosive.

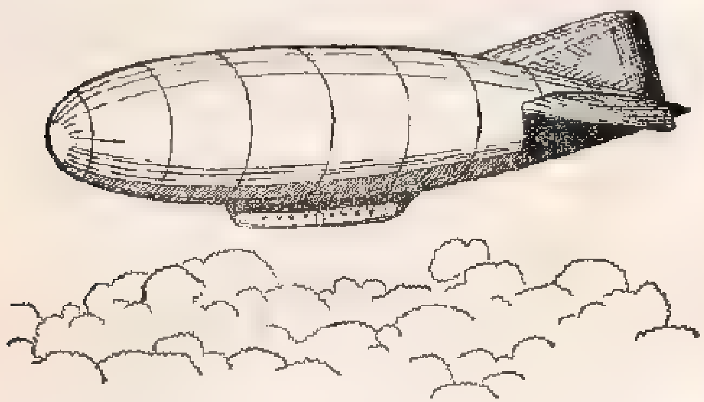

Fig. 32 An airship

The first real aircraft was made in 1903 through the inspiration of further studying the wings of flying birds and kites. The properties and structure of aircrafts have been greatly developed in the last decades. Aircrafts have been changed from propeller to jet; speed from several hundred kilometers per hour to supersonic; from manual operation to radio

control; from aluminium aircraft to heat resistant all titanium aircraft. A great variety of new aircrafts emerge constantly (Fig. 33). At present, space shuttles which rush through the atmosphere already exist.

Now let's see how air helps the aircrafts to fly.

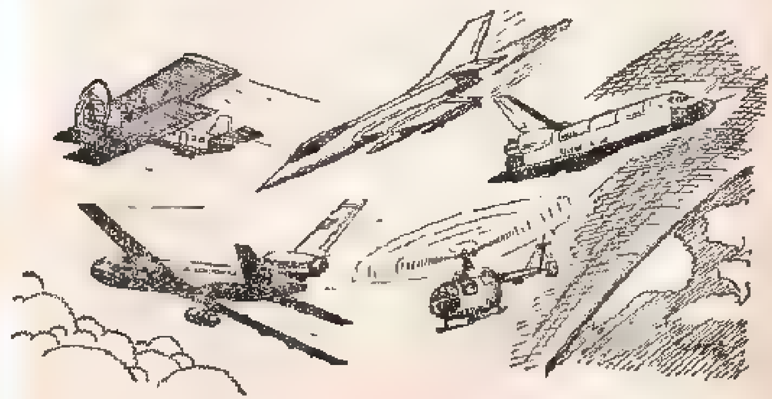

Fig. 33 Various kinds of aircrafts

Why Can Aircraft Shoot into the Sky

Differs from balloons and airships, aircrafts fly into the sky without depending on the filling of lighter gas for obtaining air buoyancy. Similar to bird, aircrafts have their own wings, but it differs in the way of flying with birds without flapping of the wings

In order to describe the principle of the lifting of aircrafts, let's first have a talk on sprayer which everybody is familiar

with. A simple sprayer (Fig. 34) consists of two parts, a vertical and an horizontal thin tube. When you give a hard blow at the horizontal end, gas will be sprayed out at a great speed. This is because when flow rate is smaller than sound speed, the larger the flow rate the smaller the pressure. Thus, air pressure at the upper top of the vertical thin tube will be lower. The low pressure will cause the rapid rising of liquid surface. Owing to the impact of airflow, liquid entering the upper top will be atomized and sprayed. Cylinder type sprayer uses piston instead of mouth blowing, but its principle is quite the same.

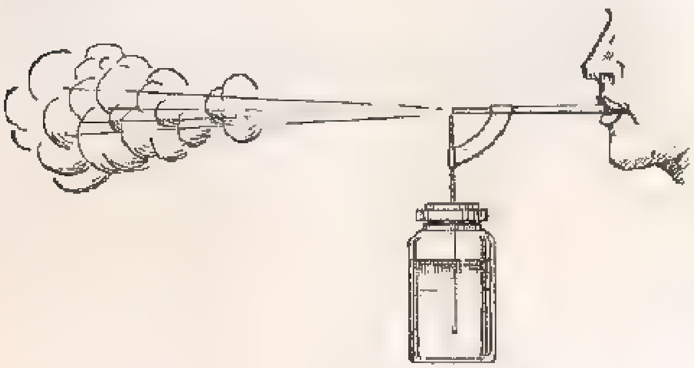

Fig. 34 A simple sprayer

The lifting of aircraft is based on the different air flowrates above and beneath the wings which causes the upward pressure larger than the downward pressure. How can the flowrate above and beneath the wings differ? This is much related

to the profile of the wings (Fig. 35). The wing of an aircraft is straight underneath, arched on the upper side, round in the front and sharp at the rear. Therefore, during flying the head-on airflow will flow separately from the upper and lower part of the wings and then join together at the rear side of the wings. But, as the airflow follows a curve way at the upper side, a straight way at the lower side and has to join simultaneously at the back. Air at the upper part runs faster than the lower, thus, the flowrate has to be larger. The larger the flowrate the lower the pressure, thus causing the air pressure beneath the wings larger than the upper. The shooting of aircraft into the sky is created by the upward force which is larger than the downward force. This upward force which aircraft bears is called hold up force or lift.

Aircraft needs to overcome air resistance to move forward. This has to be accomplished by the engine. A jet engine is a

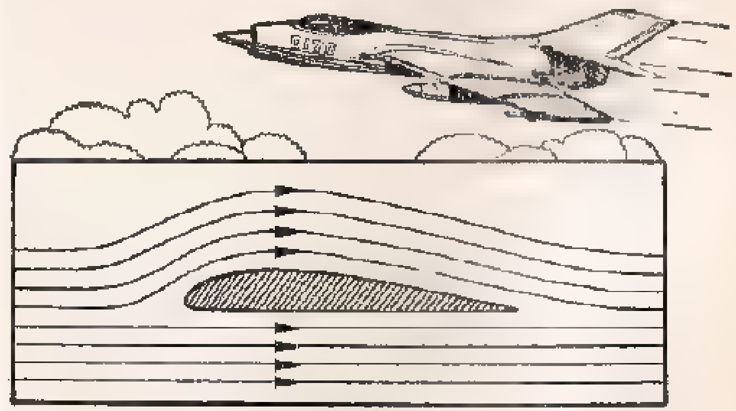

Fig. 35 The principle of the flying of aircraft

long cylinder, air enters into the compressor from the front entrance successively while flying. Compressed air will then enter into the combustion chamber. Fuel will combust during air compressing thus causing the gas to expand acutely, and eject at a high speed from the rear ejection tube. The larger the backward ejection force, the larger the frontward reacting force of air to aircraft. Aircraft moving forward depends on this reacting force to overcome the resistance of air

So, it is clear that no matter whether aircraft lifts or goes forward, it cannot be accomplished without the support and assistance of air. This kind of support and assistance comes from the collective strength of oxygen, nitrogen or rare gas respectively.

Quite a lot of things depend on the help of the air family. The widespreading application of compressed air in industrial production, transportation etc. bring us many conveniences.

CHAPTER VI

THE MAGICAL EFFECT OF COMPRESSED AIR

Air consists of quite a number of oxygen molecules, nitrogen molecules as well as some other gas molecules. The distance between these molecules remains constant in air under certain temperature and pressure. Therefore, the number of molecules is constant in per unit volume. Usually when we talk about common air, it refers to air under normal temperature and normal pressure. The pressure is approximately 1 atmosphere. If we adopt compress method and compress common air from a vessel containing two litres into a one litre vessel. It is obvious that the molecules in compressed air is more concentrated. The number of molecules per unit volume doubled (Fig. 36).

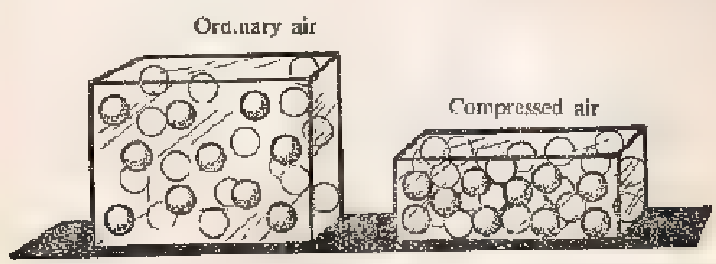

Fig. 36 Normal air and compressed air

Air molecules aren't stable in the vessel. They always dash around madly. The impact of air molecules to the wal of the vessel cause the formation of air pressure to the wall. The more the number of molecules, impacting the wall per unit area, the larger the pressure. Certainly, compressed air where molecules are concentrated possesses larger pressure than common air. That features compressed air. For a cylinder with a piston in it, if compressed air is filled from the left and common air from the right, then the pressure born by the left side of the piston is higher than the right. The piston will be pushed by the compressed air to the right (Fig. 37) Why cannot we obtain power by compressed air in this way? This is the secret of the application of compressed air.

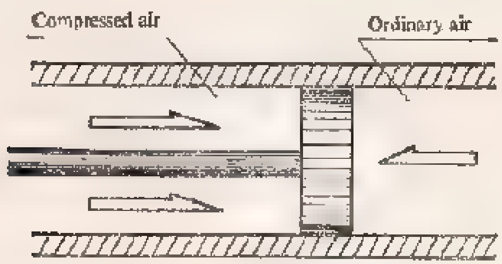

Fig. 37 Compressed air pushes the piston

How Does Air Pick Work in Coal Mining

Perhaps you have seen coal miners operating air picks (Fig. 38) either from the movies or photos. The word air here refers to compressed air. There is a cylinder with a movable pis-

Fig. 38 Coal miner operating air pick

ton in the air pick. Compressed air enters the air pick through a rubber tube, and takes turns flowing into the front and rear end of the cylinder through the help of a sliding valve but do not flow directly into the cylinder. The piston moves forward when compressed air enters the rear end and moves backward when enters the front. In this way, owing to the continuous and rapid front and backward movement of the piston in the cylinder, the bit in front of it moves forward and backward continuously and rapidly (Fig. 39). Thus excavation can be accomplished by the repeatedly percussion of bit to the coal surface.

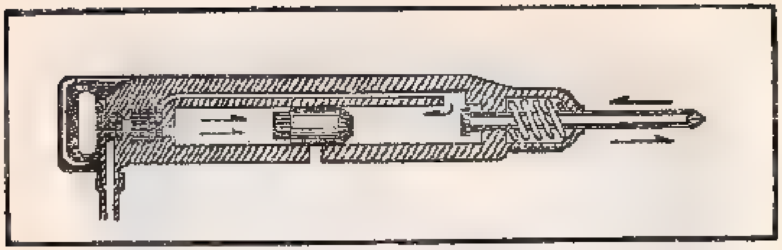

Fig. 39 The structure of air pick

According to the views nowadays, air pick for coal mining is really not a new technology, but in comparison with the old manual mining method, it greatly decreased the labour intensity of miners and increased the excavation efficiency.

Pneumatic tools similar to the air pick are riveting guns, air hammers for forging, air drills for drilling.

Air-jet Weaving Without Shuttle

It is not difficult to understand the principle of applying compressed air to pneumatic tools such as air picks, air drills, air hammers etc. But you might feel surprised if somebody tells you that compressed air can be used for weaving. Since the old days, shuttle with yarn has been used to go through warp for weaving. How can weaving be done without shuttle?

In fact, this is not difficult to understand. The above-mentioned fire extinguisher injects high pressure carbon dioxide gases which brings on the ejection of liquid. Compressed air is a kind of air with high pressure, and can form a strong airflow when ejecting. This strong airflow can be used for shot blasting to clear away rust on steel plates, for spraying paint

on automobiles, doors and windows (Fig. 40). Why cannot air-jet be used for weaving?

Cloth which we normally wear comes from yarn weaving. The transverse yarn is called weft and the vertical yarn is called warp.

Fig. 40 Spraying paint

The warp is arranged in two layers up and down tightly and neatly on the weaving machine. The two warp layers mutually exchange their positions after the weft passes through. The upper into the lower, the lower to the upper. Then the weft passes through again reversely. Weft passes in this way between the two warp layers and cloth are then produced.

In a common weaving machine, shuttle is used to bring the warp through. This means that shuttle is used to go be-

tween the warp. The so-called air-jet weaving is using the ejection of high speed airflow instead of shuttle to accomplish the job. So the scene of shuttle working back and forth cannot be found in this case. Compressed air ejects through a special nozzle and forms airflow, which will draw the weft coming out of the bobbin at the nozzle and pass it between the two warp layers. This kind of weaving method is of high speed, high quality. It greatly reduces the noise of the workshop and obviously increases efficiency.

Hovercraft Which Bears Bumping

Have you ever heard about hovercraft? It is a kind of transportation instrument which uses compressed air instead of wheels. Automobiles which we normally use have wheels and runs steadily on a smooth road. But it bumps and swings along a rough road and makes the passengers very uncomfortable. It will even bog down, while crossing a marshland. Train seems quite stable, but railway track has to be laid for its wheels to run on. This needs quite a great amount of man power and materials. Hovercraft needs neither wheels nor railway tracks, moreover it runs smoothly (Fig. 41).

High speed rotating fans and some air nozzles are equipped underneath the hovercraft. A compressed air cushion will be formed underneath the hovercraft when air is ejected through the nozzles. The pressure of compressed air underneath the hovercraft will certainly be higher than that of the common air above it. So the body will suspend owing to the upward pressure it bears. This hovercraft is able to run

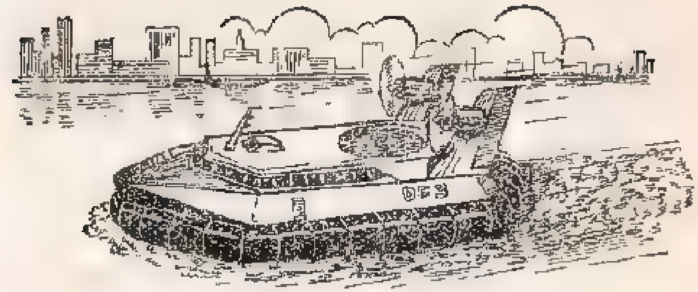

Fig. 41 Hovercraft

over the bumpy road without tossing, it can easily cross the muddy marshland, it can overcome the frictional force between the wheel and the road, therefore power can be saved.

There are quite a lot of other usages for compressed air. For instance, the application of compressed air in diving operations for drain off water and keep off water, in aircraft for fuel transportation, in trains and automobiles for braking, in buses and trolleybuses for opening the doors etc.

From the abovementioned, we can clearly see that air, no matter its individual members (oxygen, nitrogen and various rare gases) or the whole family itself has contributed greatly to us. Naturally, we ought to double treasure air who is our fully deserved close friend. Nevertheless, people often forget this in developing industry and increasing production, thus causing serious air pollution in certain areas. To eliminate pollution and protect air is the most pressing task confronting us.

CHAPTER VII

ELIMINATE POLLUTION, PROTECT AIR

How can we eliminate air pollution? This is just like a doctor inspecting a patient. First of all, he needs to know the patient's condition, investigates the cause of disease, only then, can he prescribe right medicine for the case.

What Causes Air Pollution

If someone asks you: Is sky blue? You will surely think the question is very ridiculous. Even children in kindergardens will definitely tell you that the sky is blue. But, why did pupils in a certain area of Japan painted grey sky in their drawngs few years ago? This is because what they saw every day is the grey sky. Owing to serious air pollution, people living in industrial cities or industrial areas can hardly see the blue sky.

Air pollution is mainly caused by waste gas emitted from plant stacks, exhaust from automobiles and other means of transportation as well as from other industrial production (Fig.

42). Waste gas includes flue dust, carbon monoxide, carbon dioxide, sulphur dioxide, carbon hydride, nitrogen oxide etc. (Fig. 43). The total amount of such waste gas emitted worldwide can possible be over 600 million tons per year.

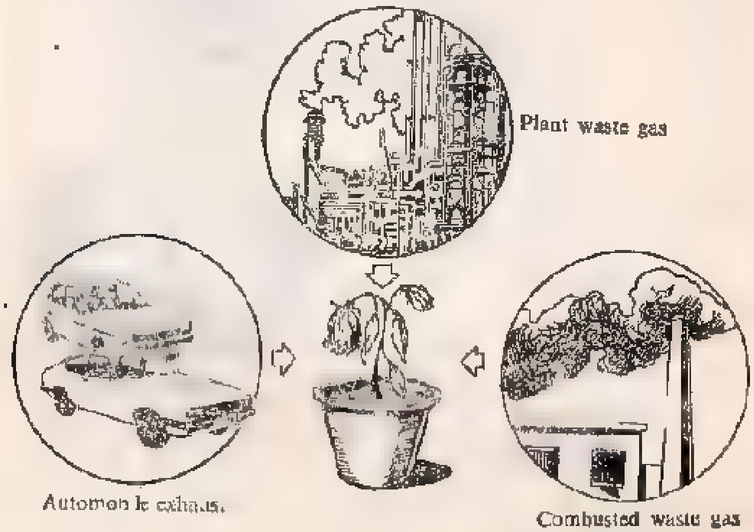

Fig. 42 The three main sources for air pollution

The combustion of coal is the main reason causing air pollution in the early days. Britain, which has an early history in developing industry, issued an announcement in 1306 forbidding London craftsmen and manufacturers to burn coal when Parliament is in session. A book published in Britain writes: "The tired visitors smell bad odor several miles away from London before seeing its roads. This is because smoke from burning coal which polluted the good reputation of this

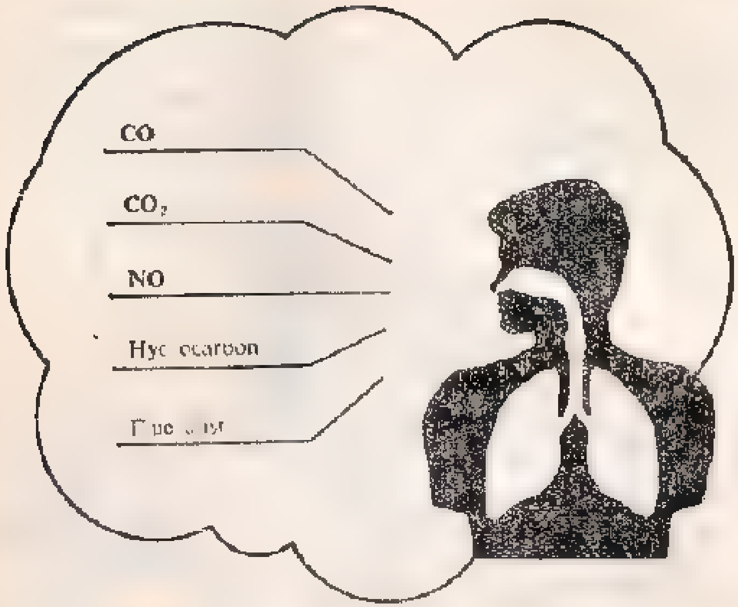

Fig. 43 The main pollutant of air

city". It is estimated that the pollutant emitted by an industrial furnace in burning one ton of coal consists 30 kg of sulphur dioxide, 1.4 kg of carbon monoxide, 9 kg of carbon dioxide and flue dust as much as 50 kg (Fig. 44).

Pollution caused by the combustion of gasoline seems very conspicuous in light with the increase of the number of automobiles. It is estimated, the total number of automobiles worldwide at present is more than 200 million, carbon monoxide emitted annually reached 200 million tons. Besides, a large number of pollutants such as hydrocarbon, nitrogen

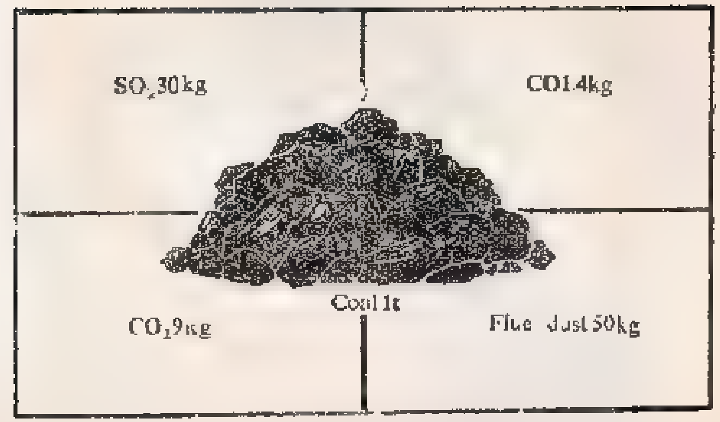

Fig. 44 Pollutant by burning one ton coal

oxide, lead compound as well as flue dust are emitted (Fig. 45). 60% of the air pollutant in U.S. comes from automobile waste gas.

What is the harm of these pollutants to mankind? Let's take flue dust as an example, it often contains a certain number of harmful metal elements and carcinogen substance. Sulphur dioxide however is a kind of gas with irritant stink and would cause respiratory system disease. London mist accident happened in 1952 causing the death of 4000 people was because of the high concentration of sulphur dioxide and flue dust in air. Although carbon dioxide doesn't harm human body directly, its increase will influence the changes of climate. Some people believe weather tends to get warmer in recent years has something to do with it. The toxicity of carbon mon-

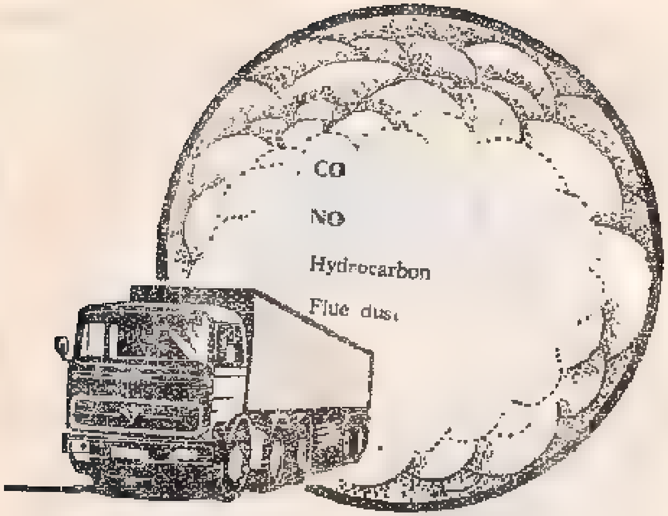

Fig. 45 Pollutant exhausted by automobile

oxide is well known, isn't gas poisoning caused by carbon monoxide? Carbon monoxide might destroy the function of blood carrying oxygen, and will even lead to death in serious conditions. As to hydrocarbon and nitrogen oxide, besides the toxicity they possesses, mutual reaction among themselves while mixing and under strong sunlight forms photochemical flue dust which is even more poisonous. A photochemical flue dust accident once happened in Los Angeles, U.S.A. caused the poisoning of several hundred people. Someone had concentrated the flue dust and applied it on a mouse's skin. It was found the mouse contracted skin cancer. The poison of other air pollutants will not all be mentioned here. The abovementioned fully illustrated air pollution is greatly endangering mankind.

Air pollution is only a part of environmental pollution. Water pollution has also created remarkable harm; furthermore, solid waste, garbage and noise also bring unfavourable influence to our daily life. Facing reality, what shall we do?

Purify the Air Surrounding Us

Since we are clearly aware of the reasons of air pollution, the next step is how to prescribe the right medicine to solve the problem.

In which way can we bring sulphur dioxide under control? We can, for instance recover it from the waste gas, and process it into sulphuric acid through chemical treatment. In this way we both control pollution of the waste gas and increase the production of sulphuric acid

Are there any measures in harnessing carbon dioxide? Carbon dioxide is regarded as waste gas in certain plants, but it is the necessary raw material in some other plants such as urea plants, sodium carbonate products etc. Why don't we combine those two kinds of plants to settle the problems of pollution and the supply of raw material? There are two plants in Shanghai which works like this. Waste carbon dioxide gas from a synthetic ammonia workshop of one plant is transported to a nearby pharmaceutical plant for producing salicylic acid. So carbon dioxide became very useful as a waste (Fig. 46).

Are there any good ways for curing flue dust? There are two ways. One way is to look for measures in eliminating the flue dust. The other is to use other fuel to substitute coal.

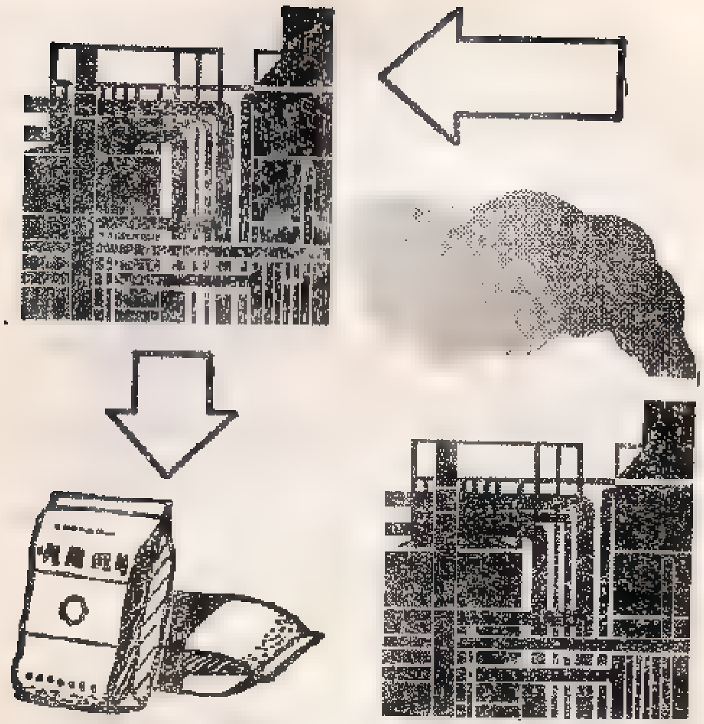

Fig. 46 Waste gas from a plant becomes raw material for another plant

There are quite a number of plants in China which obtained good results in eliminating flue dust.

Waste gas of which we have discussed above are either waste gas emission from technological process or from stacks after the combustion of fuel. Although the amount of this kind of waste gas is rather substantial, but it is quite concentrated. The location of emission is fixed, thus easier to adopt measures. It is quite difficult to harness the pollution of au-

tomobile which runs around at all places and poisons everywhere. Measures which can be adopted are to improve the quality of fuel, to reform the structure and outfit of automobiles, to treat waste gas in the automobile as well as to adopt non-pollution fuel after combustion.

In recent years, the most remarkable way of harnessing is to let the waste gas pass through a zone of catalyst for eliminating most part of poisonous gas before exhausting. There is a kind of a very effective catalyst which is capable to add oxygen to the poisonous carbon monoxide thus forming non-poisonous carbon dioxide. The catalyst is also capable to remove the oxygen from nitrogen oxide to form nitrogen. A test done by someone in Japan showed that if a catalyst of ferrous oxide is fixed in the exhaust pipe, the amount of the kind of gas like nitrogen oxide will reduce by 90% in the exhausted waste gas.

Nothing in the world is difficult for one who sets his mind on it. We are convinced that, through the unremitting efforts made by scientists, air surrounding us will surely become cleaner!

CHAPTER VIII
WATER IN NATURE

If we take air as our closely associated friend, besides it, water can be considered as another close friend to mankind Do you know, the weight of water in a human body occupies over 70%. It is foreseen that human life cannot exist without water. The importance of water is not merely of the above-mentioned reason. Water is the essential element for the existance of animals and plants and plays an outstanding role in social production. If there is no water, there would be no steam locomotives, no food, no chemical and light industry production can be carried out. Electricity cannot be generated without water, so is steelmaking. 200 tons of cooling water is required for making one ton of steel; 300 tons of industrial water is required for the production of one ton of paper. The amount of water used in agriculture might be even more than in industry. So it is not excessive for mankind to call water as the cradle of life, the lifeblood of agriculture, the most precious resource. How about the distribution of this precious resource on earth? And how did mankind use it?

Water Covers 3/4 of the Earth Surface

Water covers 3/4 of the total area of the earth where we live. The total amount of water on earth calculated according to volume occupies 1.36 billion cubic kilometers of which seawater covers 97%, glacier, ice and snow of high mountains cover 2%. Rivers, lakes and underground water on land cover merely 1%. Besides, a small amount of water in the atmosphere covers 0.001%. Thus it can be seen that most of the water in nature is in the sea.

Though the amount of water greatly differs between ocean, land and atmosphere, but they form the three indispensable aspects for water to circulate in nature. It is estimated, about 125,000 cubic kilometers of water evaporate from the oceans to the atmosphere annually. The water vapour in atmosphere changes into rain and snow while cooling, then it turns back to the land and flows into the rivers. Water in rivers absorbs some salt from soil and rocks while flowing, and flows along the direction of "lots of rivers flow into the ocean", then returns to the ocean.

Worth mentioning is the evaporation of moisture from the earth especially the evaporation of moisture from the ocean is beneficial for the readjustment of atmosphere temperature. The evaporation of moisture is the process of changing water from liquid to gas. This process requires absorption of heat. About 1/3 of the heat transmitted from the sun to earth is absorbed mainly by the evaporation of moisture from the ocean. In this way, air temperature would not go up too high. If this 1/3 of heat is not absorbed, temperature on the earth surface would be too high for us to live on. Certainly, too low temperature also bring difficulty for mankind to survive. The temperature on the earth surface would drop obviously if too much heat from earth is given out to the outer space. Water vapour in

atmosphere obstructs the heat diffusion of the earth, enabling to maintain a certain temperature on earth.

Another important reason which enables not very big changes of earth temperature is because that the specific heat of water is rather high. The so-called specific heat is the heat required by one gram of matter to rise one centigrade of temperature. Water absorbs heat not only when transforming from liquid to gas, but also from low temperature to higher temperature. This is why we need to heat water successively for turning it from cold to warm and then to boiling water. Rather high specific heat of water means the requirement of heat for one gram of water to rise one centigrade is quite high. For instance, the specific heat of water is 5 times higher in comparison with rock. This means, for the same quality of rock and water, if they absorb the same amount of heat, rock will have a temperature increase of 50°C, but water only 10°C. On the contrary, if rock and water lose the same amount of heat, rock will have a temperature decrease of 50°C, but water only 10°C. When sun shines on earth by daylight, water, mainly seawater is able to absorb a great amount of sunheat, so that the earth temperature, especially the temperature near seaside would not be that high. At night heat distributed by seawater enables the temperature would not to be too low. This is the characteristic of maritime climate of which air temperature doesn't change very much. As for inland areas which is far from the seas and oceans with only rocks and soil, sudden cold or warm will occur. This is called continental climate. Because there are rocks everywhere on the moon, so the temperature there can reach 123°C and drop to -132°C. The

difference in temperature to one's surprise might reaches 270°C. Evidently, sea and ocean greatly assist us in living at a suitable environment on earth.

Ocean — A Treasure-house for Mankind

Ocean not only plays an important role in climate adjustment, but also brings us abundant treasures.

Differs from the water of river, well and spring, seawater tastes salty and bitter. This is because it contains about 3.5% of salt, some even reaches 4.2%.

There are quite a number of varieties of salt in seawater, of which sodium chloride ($NaCl$) is the most. Besides, there are magnesium chloride ($MgCl_2$), potassium chloride (KCl), sodium bromide ($NaBr$), magnesium sulphate ($MgSO_4$) etc. The total amount of salt could reach 5,000,000 billion tons.

Talking about elements, about 2/3 of the elements among the 107 we know can be found in seawater. Besides chlorine and sodium which are the highest, the content of magnesium, sulphur, calcium, postassium, strontium and lithium is also considerable (Fig. 47).

Magnesium is an indispensable material for aircraft, automobile and flare bomb. Magnesium in seawater amounts to 1,767,000 billion tons. If 100 million tons of magnesium from seawater is extracted every year, after a million years the magnesium content will drop merely from 0.13% to 0.12%. About 60% of the magnesium output comes from seawater. World output of noble metal — gold, is just over one thousand tons annually, it indeed can be recognized as the most precious thing

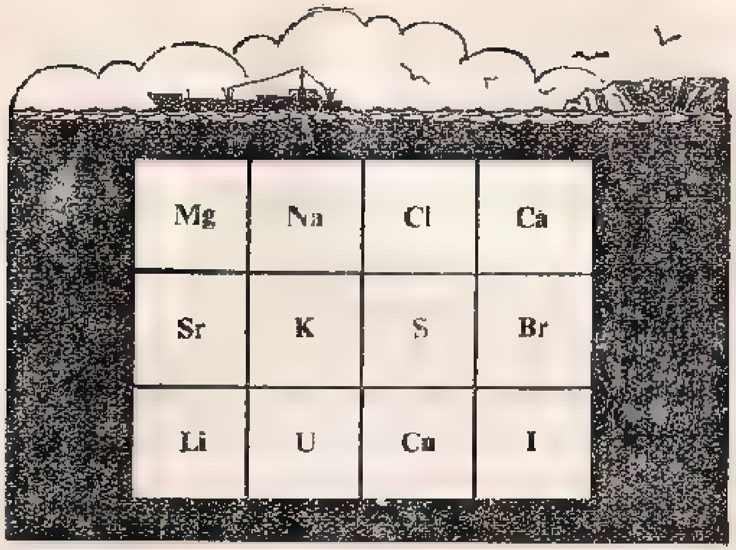

Fig. 47 The main elements in seawater

because of its scarcity. But gold content in seawater is not rare, it contains 5.5 million tons. If all of the gold in seawater is extracted and piled together it will be about 300,000 cubic meters. Uranium is greatly needed for atomic bomb as well as for the development of nuclear power. Its consumption rises year by year However, the amount of uranium ore worthwhile mining on land is only 2 million tons. It is estimated that uranium ores will be depleted in 2000. But the uranium reserves in seawater is 2000 times more than on land. It is about 4 billion tons. Many countries have been carrying out studies and experiments concerning the extraction of uranium from seawater since 1956, and have obtained remarkable results. There are also quite a number of other metals in seawater

such as copper, nickel, manganese, cobalt etc. Although its percentage content is not that high, but owing to the total amount of seawater, the total amount of deposit is larger than on land

Content of some elements in seawater (μg/l)

Element	Content	Element	Content
Chlorine	19,350,000	Phosphorus	88
Sodium	10,770,000	Iodine	64
Magnesium	1,290,000	Barium	21
Sulphur	904,000	Indium	10
Calcium	412,000	Molybdenum	10
Potassium	391,000	Nickel	6.6
Bromine	67 300	Zinc	5
Strontium	8,100	Uranium	3.3
Boron	4,450	Vanadium	1.9
Fluorine	1,300	Titanium	1
Lithium	170	Aluminium	1

1 gram = 1,000,000 μg.

The abovementioned is restricted only on resources in seawater. There are also abundant resources in the seabed under the seawater. Besides metals, the reserves of petroleum and natural gas are also abundant. Furthermore, there are over 160,000 kinds of various living beings including sea animals and sea plants. They look bright and colourful and made the ocean a beautiful world with their thousands of varieties of postures (Fig. 48).

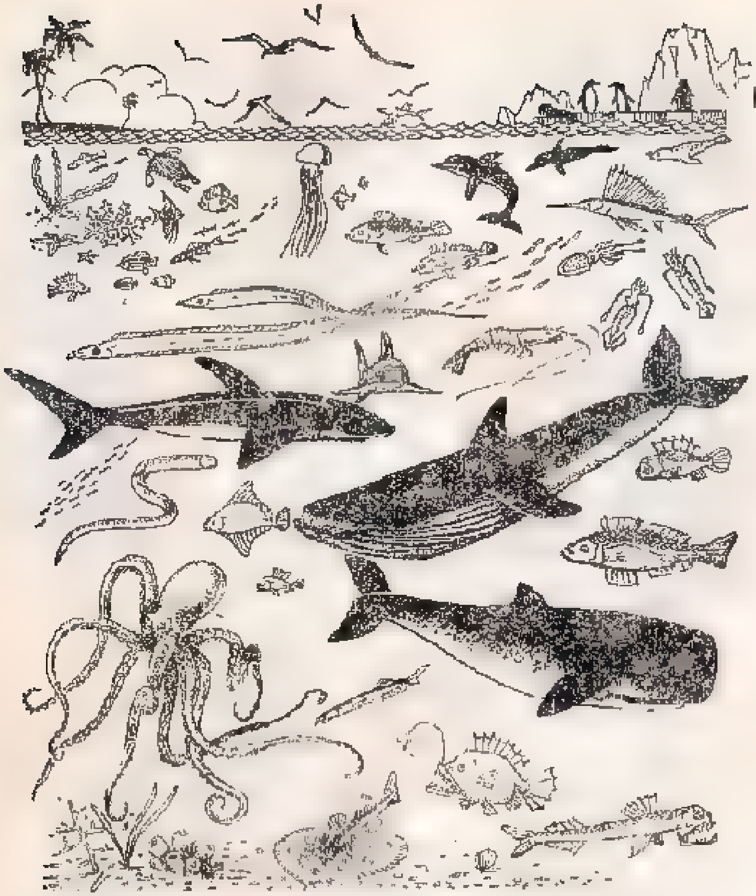

Fig 48 Sea plants

Water in Rivers and Lakes

Though seawater contains so rich resources of minerals and living beings, it is not suitable for the usage of mankind in daily life and production. It is also difficult to obtain water from glacier, ice and snow from high mountains and deep underground water on earth. So, rivers and lakes are the main sources of supply of water for mankind.

The salt content in rivers is much lower than in the sea and ocean, the main salt content in river is calcium salt (calcium carbonate), unlike seawater which mainly contains sodium salt (sodium chloride). Scientists believe that this is because the formation of shells (consist of calcium carbonate) of the large amount of shell fish in oceans consumed large quantities of calcium. Besides calcium salt, river water contains also chloride, sulphate and carbonate of various metals such as sodium, magnesium, potassium, aluminium, iron etc., as well as organic matters and gases soluble in water. The kind and content of impurities in rivers differs in accordance with rocks and soil of different areas through which rivers run through.

The circumstances of lakes differ from rivers. Salt content in fresh water lake differs from salt water lake. Lakes on high mountains are converged by rain and snow, their salt content is only 0.01%; but the salt content of salt water lakes is normally between 2~3%. Salt content of some lakes is even higher than seawater.

The most noticeable one among the high salt content lakes is Dead Sea. It is located at the west part of Asia with an area of about one thousand square kilometers.

While talking about lakes, people will surely call to mind those plenty of lands with beautiful sceneries in China such

as Dongting Lake, Boyang Lake But you cannot find any fish in the Dead Sea, nor one piece of sea plant. Even on the shore surrounding it cannot grow a blade of grass. No fish in the water, no rice growing on the shore, nor can you begin to talk about plenty of lands. It is not only without living beings that makes Dead Sea peculiar. It was told that once there happened an admiring story. Once upon a time, a Roman general determined to put to death several slaves he captured while passing there with his soldiers. He ordered his subordinates to have the slaves in bonds and shackles and then to throw them into the lake. But to their surprise instead of sinking, the slaves were pushed by the waves to shore. This greatly frightened everyone, so was the general who thought that it was the spirits in the Dead Sea who blessed those slaves. So, daring not to neglect, he immediately ordered to set free the captured slaves.

Is there really any spirits in the Dead Sea? Of course not. But is the story compiled without any background? Also certainly not. Even now, the Dead Sea remains the same, visitors can lie on the surface reading newspapers, books without sinking (Fig. 49).

In fact, this phenomenon isn't strange. The reason why people won't sink in the Dead Sea is because of the high salt content in water. This is the same principle that normally egg sinks in clear water but floats in dense salt water (Fig. 50) When a certain amount of salt is solved in water, the density i.e. quality per unit volume will be increased. In physics, the

famous Argimid principle showed us, when an object sank in liquid, the buoyancy it bears, equals to the weight of the part of liquid it removed. If the density of the object is larger than the liquid, then it will sink, if smaller than the liquid, it will

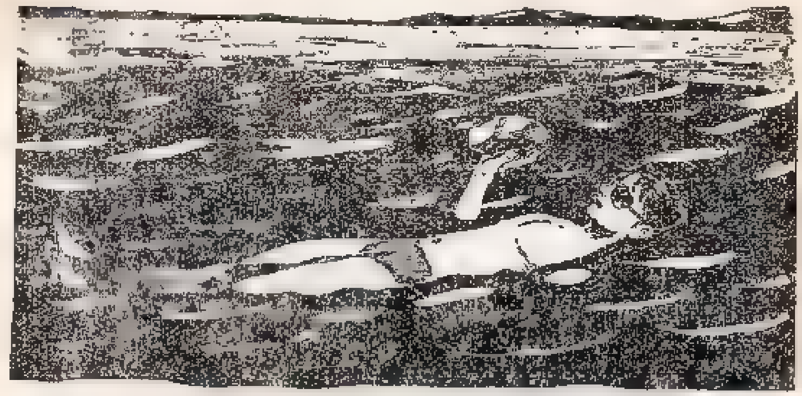

Fig. 49 Man lying on the Dead Sea will not sink

float. The density of pure water is about 1 g/cm^3, and will increase as the salt content in water increased. The salt content in Dead Sea is about 25%, 7~8 times more than seawater. Its density is over 1.172 g/cm^3. Density of a human body is about 1.05~1.09 g/cm^3, greater than the density of common natural water (1~1.03 g/cm^3), but smaller than that of the Dead Sea. So, even those who cannot swim, don't need to worry when lying on the Dead Sea.

The density differs not only between pure water and salted water, but the density will also change notably while pure water freezes. The feature of this change is that, when

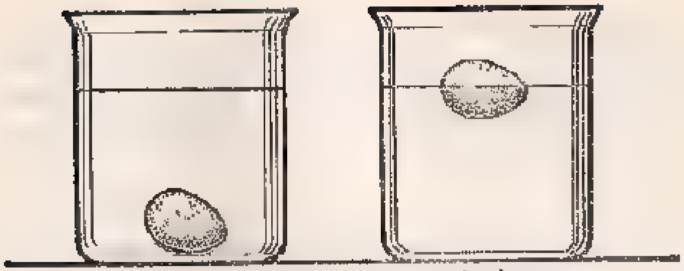

Fig. 50 The sink and float of an egg

freezing, the volume of water increases instead of shrinking and the density becomes smaller instead of larger. This turns out just contrary to the heat expansion and cold shrink principle of common matters. Owing to the abovementioned, ice is able to float on the water surface instead of sinking. Frozen water in a glass will break the glass. But why the density of ice is smaller than water? We must investigate the difference between the structures of ice and water.

CHAPTER IX

THE SPECIAL CHARACTERISTICS OF WATER

When studying the properties of matter, people often use to try to seek reasons from its structure. This is the scientific way summarized by years of experience Since the last two hundred years, scientists have always been paying close attention to the study of the constituent and structure of water, on which they have spend most of their endeavors. Even before late 18th century, people still considered water as one element, instead of a compound consisting of two elements. By experiments, Karwendish showed burning hydrogen in air produces water in 1781. Several years later Lavash determined the weight constituent of the two elements hydrogen and oxygen in water, but not accurate. In 1803, Dordon posed atomic theory and considered water consists of two kinds of atoms, hydrogen and oxygen. He didn't pose the concept of molecules and misidentified that the ratio of hydrogen and oxygen atoms in water is 1:1. Afgadro posed the molecule theory in which he distinguished molecule and atom in 1811. He pointed out water as a matter consists of water molecule, and water molecule consists two kinds of atoms, hydrogen and

oxygen. Through experiments, he correctly determined the proportion ratio of hydrogen to oxygen is 2:1, the molecular formula of water is H_2O. At present, electrowinning experiments of water can be used to accurately illustrate this scientific conclusion which was not easy to achieve.

Water Decomposition by Electrifying

The so-called water electrowinning is the decomposition of water to hydrogen and oxygen by electrifying. The ratio of the number of atoms of hydrogen to oxygen is determined by the volume ratio of the two gases produced during decomposition.

Figure 51 shows an apparatus which is able to decompose water by electrifying. First, take off the stoppers on both sides of the glass tube and fill water from the middle funnel (some suphuric acid or sodium hydroxide solution is added to speed up the reaction) till the glass tubes on both sides are full. Put back the stoppers and connect the two electrodes with direct current, gas bubbles will immediately emerge on the electrodes and will be concentrated at the upper part of the two glass tubes. The volume of gas in one tube is twice as much as the other. Through examination, we'll find the smaller volume is oxygen, the larger one is hydrogen.

The abovementioned experiments proved that the volume ratio of hydrogen to oxygen through electrifying is 2:1. Considering the gas density of hydrogen is 0.09 g/l and oxygen 1.429 g/l, it can be calculated that the quality ratio of hydrogen to oxygen is 1:8.

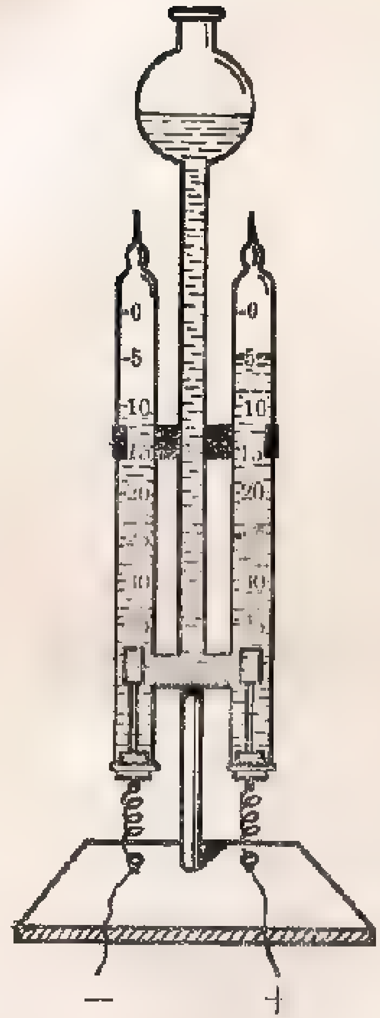

Fig. 51 Water decomposition by electrifying

$$\frac{\text{quality of hydrogen element}}{\text{quality of oxygen element}} = \frac{2 \times 0.09}{1 \times 1.429} \approx \frac{1}{8}$$

Because we know atomic weight of hydrogen is 1, oxygen is 16, therefore quantity ratio of hydrogen to oxygen atom in water molecule is 2:1.

$$\frac{\text{quantity of hydrogen atom}}{\text{quantity of oxygen atom}} = \frac{1+1}{8+16} = \frac{1}{0.5} = \frac{2}{1}$$

According to the results of the experiments, the molecule weight of water is 18, it can be determined that each water molecule consists of 2 hydrogen atoms and one oxygen atom. The molecular formula should be H_2O.

Not only water has its fixed composition, experiments showed that all pure substances have their fixed composition. This is the famous definite composition principle.

Atoms not only have a fixed amount in composing molecule, but also a certain structure i.e. a definite combination form and angle. Hydrogen molecule and oxygen molecule consist dual atoms and are of rectilinear structure, but water molecule is not of rectilinear shape. Scientific experiments showed that water molecule is of angle shape of 104.5° (Fig. 52). The chemical reaction of water electrowinning is shown in schematic drawing Fig. 53.

Its chemical reaction formula equals

$$2H_2O \xrightarrow{\text{electrifying}} 2H_2\uparrow + O_2\uparrow$$

After we are clear of the composition and structure of water molecule, how can we explain water's special characteristic which violates the principle of 'Expansion while heating, shrink while cooling"?

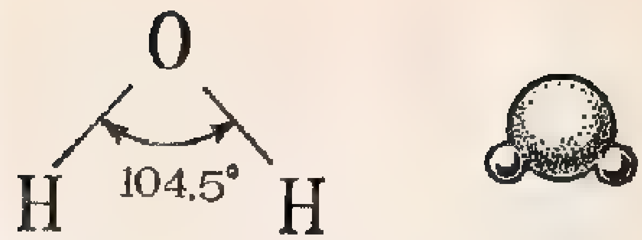

Fig. 52 The structure of water molecule

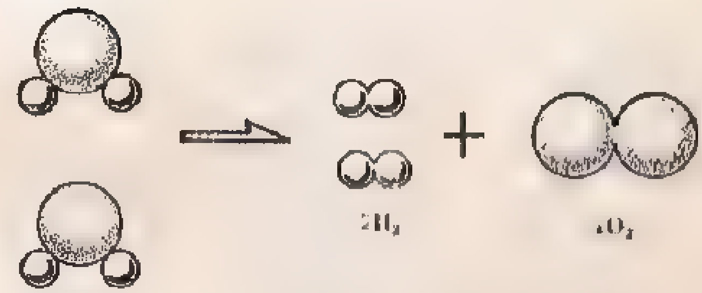

Fig. 53 The decomposition of water

Water Volume Increases While Freezing

Normally, the density of common liquid increases with volume decrease as temperature decreases. But the density of water turns to be the maximum (1 g/cm³) at 4°C and will decrease as volume increases accordingly with the further decrease of temperature. Water freezes at 0°C and its density will drop to 0.9168 g/cm³. The remarkable changes of density causes a 1/10 increase of volume for water while freezing. So, that is why ice floats freely on rivers

Why does density reduces remarkably when liquid water changes to solid ice? This is because when the angle shape water molecule concentrates to form liquid or solid, it doesn't pile up smoothly. There are different ways for molecules to combine. When water is in the form of liquid, it often happens that only quite a few molecules connect with each other, but when water turns to ice with a definite geometric shape, it happens that quite a number of water molecules mutually connect together according to a certain angle, shown on figure 54. From the figure you can see that this is a kind of incompact structure. So, when water freezes, its density will decrease and volume will increase.

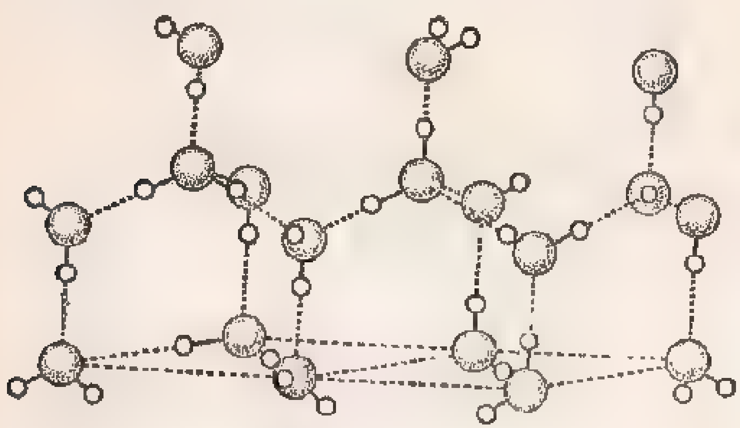

Fig 54 The structure of ice

Owing to this angle shape structure of water molecule and the mutual combination function among themselves, a lot of heat will be needed to melt solid ice or to boil liquid water.

Water's melting point and boiling point are all rather high. This is another characteristic of water.

Water Freezes at 0°C and Boils at 100°C

Comparatively speaking, melting point and boiling point of water are high. Melting point and boiling point of substances with similar chemical structures, normally increase as the molecule amount increases. But water is an exception. The chemical structure of water is similar to the structure of hydrogen sulphide (H_2S). The molecular weight of hydrogen sulphide is 34, larger than water (18). According to general law, melting point and boiling point of hydrogen sulphide should be higher. But facts show the contrary, melting point of water is 0°C, hydrogen sulphide -85.5°C, the boiling point of water is 100°C, hydrogen sulphide -60.3°C. The reason of this unusual phenomenon is that the combination function among water molecule is even stronger than among hydrogen sulphide.

But, why does water freeze at 0°C and boil at 100°C (Fig. 55)? We have to begin the story from the vapour pressure of water. It is well known that water not only turns to gas while boiling, but also gasifies while evaporating. Water in an uncovered cup will evaporate several days later. Where does it go? It has turned to vapour and escaped into the air. Things will be different if water is put into a sealed vessel. Needless to say several days, even several months water in the vessel will not evaporate. This is because, in such a case, the vapour evaporated can't escape, but dashes along the limited

space above the water. Gasified water molecule will impact with each other on the wall of the vessel. There might be a certain portion which will impact the water surface and return back to liquid.

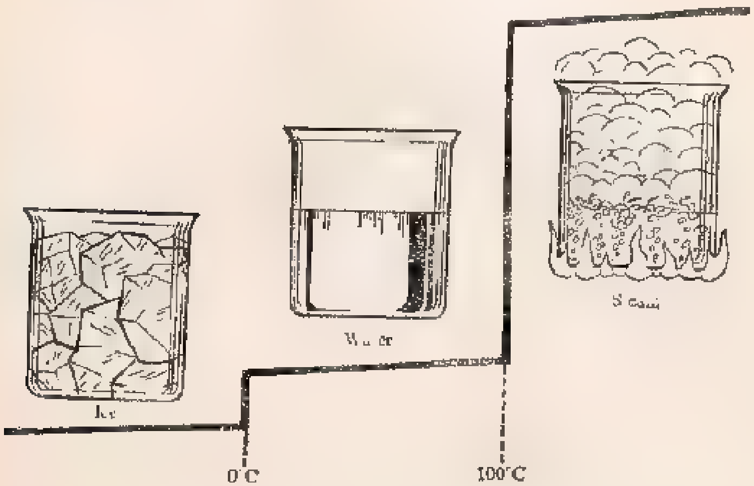

Fig 55 The melting point and boiling point of water

Two procedures are carrying out in the sealed vessel, first is the evaporation of water to vapour, second is the condensation of vapour to water shown in Fig. 56. At the beginning, the evaporation amount is larger than the condensation amount. Later, the condensation rate will speed up and the evaporation rate will slow down gradually in accordance with the more and more vapour molecule on the water surface. Finally, the evaporation rate happens to be the same with the condensation rate. At this time, though evaporation and condensation are

carrying on, the amount of liquid will no more decrease, the amount of vapour will no more increase as well. An equilibrium state might then be obtained. Vapour in such an equilibrium state is called saturated vapour. Pressure created by the impact of this kind of saturated vapour to the wall of the vessel is called saturated vapour pressure, normally called vapour pressure.

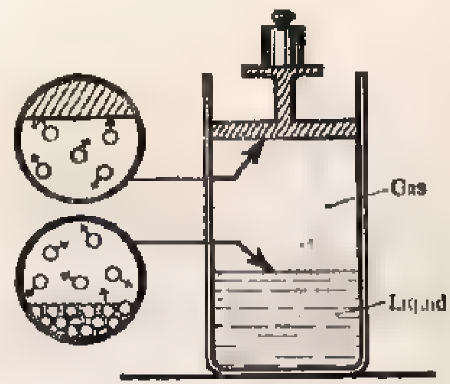

Fig. 56 Evaporation and condensation of liquid

Vapour pressure will increase accordingly in accordance with the increase of temperature. This is because the evaporation of liquid is a procedure of heat absorption. The increase of temperature gives benefit to the absorption of heat, the same to evaporation. When the evaporation rate speeds up, the amount of vapour molecule per unit volume will increase. The kinematic rate of vapour molecule will also speed up owing to the increase of temperature. The vapour pressure created by the

impact of vapour molecule to the wall of the vessel wil. certainly increase, because of the increasing amount of molecules and its increasing speed.

The increase of vapour pressure of water in accordance with the increase of temperature is shown as follow:

Temperature (°C)	0	25	50	75	100
Vapour pressure (atmosphere pressure)	0.006	0.03	0.12	0.38	1

Liquids will boil when the vapour pressure increases to equal the outside pressure. This means the vapour pressure is sufficient to withstand the external pressure. The boiling temperature is called boiling point. As to water, the vapour pressure is one atmosphere pressure when the temperature increases to 100°C. This is the external pressure under normal case. So, normally the boiling point of water is 100°C.

It doesn't mean that in all circumstances the boiling point of water is fixed to 100°C. The boiling point of water is only 72°C at the peak of Mount Qomolongma. What is the reason (Fig. 57)? This is of course not owing to the increase of the vapour pressure of water at the peak. Vapour pressure of liquid will never change if the temperature is fixed. The reality is that the atmosphere pressure at the peak is far lower than that on the plain.

It is well known that the atmosphere pressure differs at different altitudes on earth. It is only at the altitude near the sea level that the atmosphere pressure is one. The higher above the sea level, the thinner the air content and the lower the atmosphere pressure. The boiling point of water will decrease accordingly. According to experiments, it will be 90°C at an altitude of 3000 meters above sea level. The peak of Mount Qomolongma is the highest point on earth, with a height of 8848 meters above sea level, water boils there at only 72°C. So, cooking is not easy to be done on high mountains. Even "boiling water" up there cannot make good tea

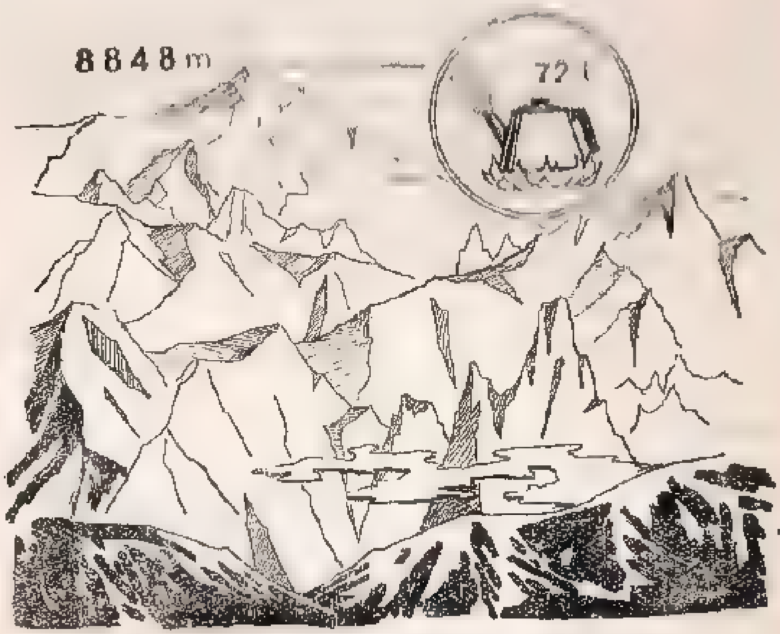

Fig. 57 At altitude of 8848 meters, the boiling point of water is 72°C

Not only liquid possesses vapour pressure, solids which are able to evaporate possess also vapour pressure. Camphor balls in wardrobes will become smaller as time passes. In winter, wet clothes hanging outdoors will dry up even if they are frozen. The abovementioned shows that solids are also able to evaporate.

The vapour pressure of solid is lower than liquid, but it increases in accordance with the increase of temperature. The vapour pressure of ice is similar to water at 0°C and equals to 0.006 atmosphere pressure. Water is able to coexist with ice at this time. This temperature is the melting point of ice as well as the freezing point of water. So it is foreseen that the melting point (or freezing point) of a matter is the exact temperature at which the solid vapour pressure of this matter equals to the liquid vapour pressure.

In conclusion, water boils at 100°C because the vapour pressure of water equals to the external atmosphere pressure (one atmosphere pressure) at 100°C; water freezes at 0°C because the vapour pressure of water equals to the vapour pressure of ice at 0°C.

Besides water density changes unusually, the melting and boiling point of water are rather high, another special characteristic of water which people paid great attention to is its outstanding ability in dissolving matter.

An Outstanding Solvent

If we drop a spoon of salt into a glass of water, we will find the salt disappears gradually in water, this process is called

dissolution. After the salt dissolves there still remains a glass of clear transparent liquid. This kind of liquid is called solution. This kind of dissolved matter like salt is called solute. Matter which is capable of dissolving solute is called solvent. Solute is not restricted to be solid, liquid or gas can also be used as solute. Solvent is also not restricted to be water, alcohol, gasoline, benzene, carbon tetrachloride etc. can also be used as solvent.

Any solution, no matter with colour or colourless, is homogeneous, clear and transparent. The salt water you have seen, after the dissolution of salt in water is a kind of uniform liquid. You cannot distinguish which is salt and which is water.

The outstanding ability of water as a solvent is it can dissolve far more greater variety of matters than any other solvents. People might exaggerate a little bit when they describe water as an universal solvent, but take water as the most vast applicable solvent cannot be considered as overpraising.

Though water is capable of dissolving a great variety of matters, various kinds of matters show different solubility in water.

An experiment can be carried out as follows: add three different kinds of matters, 200 g of cane sugar, 40 g of salt, 0.5 g of white lime into three glasses filled with 100 g of water each. After completed mixed, you will find the cane sugar which is the largest in quantity is wholly dissolved. The solution is clear and transparent. Salt which is smaller in quantity

also mostly dissolves, but there is still a small undissolved part that remains at the bottom. White lime which is the smallest in quantity mostly undissolves. It shows that in same amount of water, the dissoluble quantity of various matters differs. It is determined, at 25°C in 100 g of water the maximum dissoluble quantity of cane sugar is 210 g, salt 36 g, white lime only 0.12 g.

Usually when we mention about the solubility of a certain matter it means the maximum dissoluble amount (g) of this matter in 100 g solvent under a certain temperature. As for gas, it is usually expressed as the maximum dissolved volume which is easier to calculate as gas per unit volume of solvent under a certain temperature.

Because water is the most convenient and common solvent, therefore, when mentioning about solubility, it normally means the solubility in water. Notes have to be made if other kinds of solvents such as alcohol, gasoline, benzene, ether, carbon tetrachloride etc. are used.

Though the solubility of matters differs, there is no matter in nature which is absolutely unsoluble. It seems that limestone ($CaCO_3$) doesn't dissolve in water, but actually its solubility in water is 0.0013 g. Normally when we say unsoluble matter, it means a matter with a solubility below 0.01 g. When the dissolution amount of a certain solute reaches the maximum in solvent, this solution is called saturated solution. Solution in which solute didn't reach the maximum dissolution amount is called unsaturated solution.

Because the solute in solution is limited by its solubility, so when a kind of unsaturated solution turns to saturated solution along with the constant evaporation of moisture, the concentration of the solution will not increase if the solution further evaporates. Then, the oversaturated part of solute will lose their hiding place and will be forced to crystallize (Fig. 58). The evaporation of brine in the sun to make salt is the utilization of this principle.

Fig. 58 Crystal is precipitated by evaporation

On the wide saltworks where the sky and sea links together, brine is first conducted to a water storage pond (primary evaporating pond) for primary evaporation, clarification, then it enters into the evaporation pond. Most of the moisture will be evaporated by sunshine and wind, thus forming concentrated salt water, furthermore, salt water will enter the crys-

tallization pond through an adjustment pond, where it evaporates continuously and later precipitates crystallized salt. Then concentration can further be made to precipitate magnesium chloride, sodium sulphate etc. besides salt in the re-evaporation pond (Fig. 59).

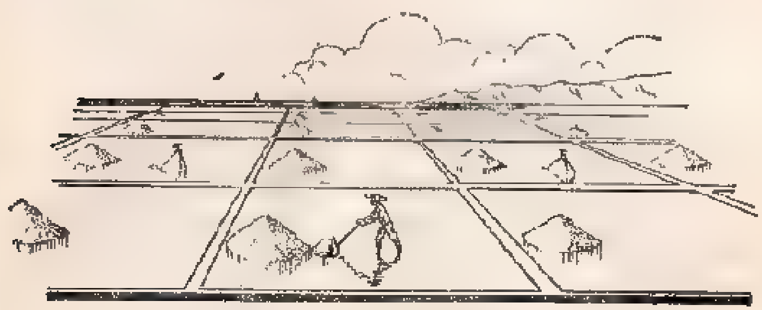

Fig 59 A scene of saltwork

CHAPTER X

THE MYSTERY OF THE DISSOLUTION OF MATTER IN WATER

Why does the solubility of different matters differs in water? And why is the solubility of some matters low in water but high in other solvents?

Similars Are Intersoluble

While studying the dissolution properties of matters, chemists discovered iodine (dark purple solid, molecule formula I_2) is difficult to dissolve in water, but easy to dissolve in carbon tetrachloride (colourless liquid, molecule formula CCl_4) solvent. Why is iodine close to carbon tetrachloride but far from water? Through further studying the molecule structures of these three kinds of matter, we might find that they possess a certain regularity (Fig. 60).

Two fully similar iodine atoms are mutually combined with each other in an iodine molecule. The two nucleuses in the molecule have the same positive charge and electrons surrounding the two nucleuses also have the same negative charge.

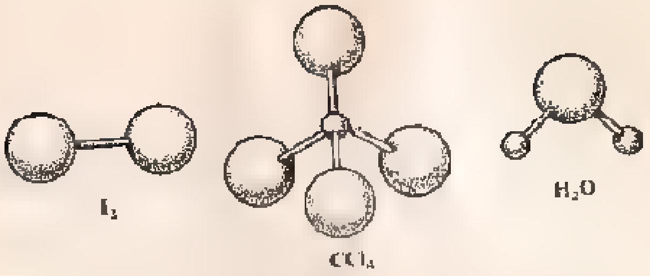

Fig. 60 The molecule structure model of I_2 CCl_4 H_2O

In the view of molecule as a whole, the distribution of the positive and negative charges is even and symmetric. This kind of molecule is called non-polarized molecule

Though the number of carbon atoms and chlorine atoms differs in a carbon tetrachloride molecule, the molecule structure is symmetric. The carbon atom is in the center position and the four chlorine atoms are distributed equidistancely around it. From the point of view of molecule as a whole, the distribution of the positive and negative charges are also even and symmetric, so this molecule also belongs to non-polarized molecule.

But the water molecule is different. The two hydrogen atoms located at one side of the oxygen atom form a certain angle. In the view of molecule as a whole, the distribution of the positive and negative charges is uneven. Because the attraction of oxygen nucleus to the electron is strong, so the oxygen side displays negative and hydrogen side displays posi-

tive in the molecule. It is likely that there exist both a positive polar and negative polar in the molecule, this kind of molecule is called polarized molecule.

It is thus obvious that iodine and carbon tetrachloride belongs to one family and are both non-polarized molecules. Their relation is quite close and is intersoluble. As for iodine and water, one belongs to non-polarized molecule, the other polarized molecule, they drift apart from each other and are not easy to dissolve.

Through a number of experiments, chemists have proven that molecules of similar structures are intersoluble This is so-called the principle of "similars are intersoluble". This principle shows that the dissolution property of matter relates to the structure and the polarity of molecule. The similars in structure and polarity are intersoluble, on the contrary, it would be mutual unsoluble.

The separation phenomenon between oil and water is owing to the weak polarity of oil molecule and strong polarity of water molecule causing them difficult to dissolve mutually. Most of the organic molecule belongs to weak or non-polarized molecule. Therefore, organic matter is normally difficult to dissolve in water, but easy to dissolve in organic solvent.

Why can ether ($C_2H_5OC_2H_5$), chloroform ($CHCl_3$) cause general anaesthesia, and why does people laugh and later lose their consciousness after absorbing laughing gas (N_2O colour less gas)? This is because the abovementioned all belongs to

weak polarized matters which are easy to dissolve in nerve centre system of rich fat (weak polarized matter), while being absorbed by human body.

Another interesting phenomenon is discovered while studying the dissolution process of matter in water. Some of the matters emit heat while dissolving, others absorb heat. What is the reason for this?

The Expansion and Hydration of Solute Particles

Heat absorption and emission phenomena are always accompanied during the dissolution process of matter. Put a beaker which is filled with water on a piece of plank with water on its surface. Insert a thermometer in the beaker and then dissolve ammonium nitrate (NH_4NO_3) in the water. You will find the temperature drops gradually along with the constant dissolution of ammonium nitrate. If your hands touch the beaker, you can feel the cold. Even water on the plank might freeze together with the beaker (Fig. 61).

Insert also a thermometer and a small test tube with ether in another beaker filled with water. Then, use tweezers to put pieces of sodium hydrate into the water. You will find the temperature rises gradually with the constant dissolution of sodium hydrate even in a small test tube, your hands will feel the heat when touching the beaker (Fig. 61).

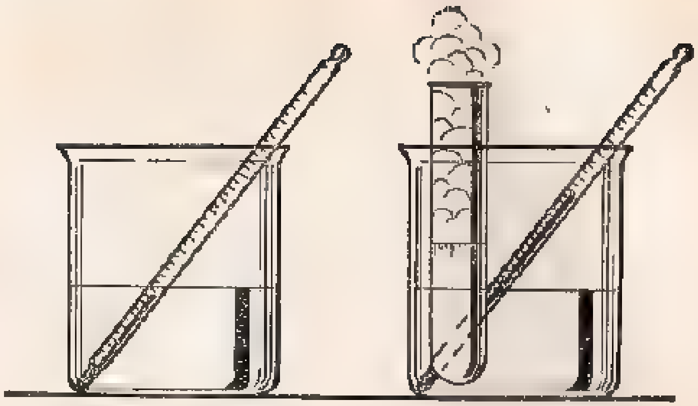

Fig. 61 Heat phenomenon of the dissolution of matter

From the two experiments, you will find two different phenomena, one shows the process of heat absorption, during which cold might lead to freezing; the other heat emission during which heat might lead to boiling. Why are the heat phenomena completely contradict as they all belong to matter dissoluble in water?

Originally, when matter dissolves in water, in one aspect, there appears a physical process where solute particles expand, this needs sufficient energy to overcome the attraction in the crystal, so it is necessary to absorb external heat. In the other aspect, a chemical process carries out simultaneously where solute particles hydrate. During hydration, it is necessary for matter to emit heat to the external. The result will be heat absorption if heat absorption is larger than heat emission. The result will be heat emission if the heat absorption is smaller than heat emission. It is determined that the dissolution of 80

grams of ammonium nitrate will absorb 6.32 kcal of heat, but 10.4 kcal of heat will be emitted during the dissolution of 40 grams of sodium hydrate.

The Strange Temper of Saturated Solution

It is known that the solubility of most solids decreases with the drop of temperature. So, normally crystal will be precipitated when the hot saturated solution is cooled (Fig. 62). This method is often used in production or in laboratories to manufacture matter.

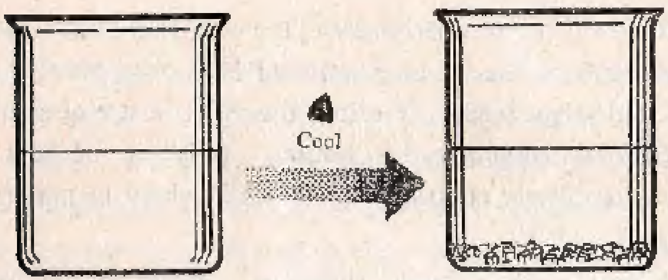

Fig. 62 Crystallization during cooling

Nothing in this world is absolute. There might be a possibility for saturated solution not to precipitate crystal, if mixing and vibrating can be avoided and the cooling process slow. This kind of solution, which exceeds the limit of saturation but didn't precipitate crystal, is called supersaturated solution.

The supersaturated solution has a very strange temper. The solution will turn to saturated one and precipitate a great number of crystals if a single crystal as small as a needle tip is added or touched to it.

Why does the saturated solution have such strange explosive temper? This is because particles in the solution, no matter molecule, ion or other particles are always on the move, dashing around madly instead of standing still. Crystal precipitated from the solution can only be formed if the particles are concentrated together orderly and arranged in orientation in accordance with the geometric shape of crystal. Crystal will not precipitate if the arrangement is not in order. It is easy to turn order to disorder but not easy to turn disorder to order. Sometimes even through arrangement a whole orientation in order cannot be achieved. Crystal cannot be formed in this way and the solution remains supersaturated. This condition sometimes might stand quite long if there is no external urge. Mixing, vibration or the addition of some pieces of crystal will play a role in urging. A small crystal might at this time turn to be the core of the formation of a great number of crystals. Thus, crystals in good order can be rapidly formed and precipitated from the solution.

CHAPTER XI

SHOULD THE WATER OF LIFE BE EVER CLEANER

The outstanding ability of water shown in the aspect of dissolving matter brought us advantages but also harm. Because of its ability, seawater turned out to be the inexhaustible treasure house, but its ability brought also environmental pollution to human beings. Water is the material force for the existence of all lives. In our daily life, about 6,600 liters of water will be consumed by an adult per day of which 2 liters for drinking, 600 liters for living, 3000 liters for industry and agriculture respectively per person in average. The pollution of water relates directly to the health of mankind and the progress of social production. Therefore, measures in all aspects must be adopted to eliminate pollution and to make the water of life ever cleaner.

The Purification Ability of Aluminium Salt

Fresh water in nature generally comes from rivers and lakes. Besides a small amount of calcium, sodium and magnesium salt, the impurities in this kind of water include suspended matters such as sludge etc., organic matters dissolved in water and gas. Normally when this kind of water is used for drinking, aluminium salt is used to purify it.

Before applying aluminium salt, water should be first held in a big tank for the settling of solid suspensions in water. This method for eliminating impurities of course can only remove large suspended matters but not small solids and suspension colloid. Aluminium salt (normally aluminium sulphate) and lime should then be added to the water to form colloid precipitation i.e. aluminium hydroxide ($Al(OH)_3$) which is produced by the chemical reaction of aluminium salt and lime in water. This colloid precipitation can absorb those small suspended matters and most of the bacteria and will precipitate gradually. The application of alum to purify water in countryside is the application of this principle. Alum is a kind of double salt containing aluminium sulphate and potassium sulphate. The required drinking water can be obtained by the application of aluminium salt for purification, and by a number of further steps including filtering, disinfecting (normally chlorine is used), deodorizing etc. The purification procedure of a waterwork is normally proceeded in this way.

The requirements for industrial water, for which special attention is paid in preventing damage caused by calcium salt and magnesium salt in water, differs from drinking water. Water which contains a certain amount of soluble calcium salt and magnesium salt is usually called hard water. The way to treat hard water for reducing the content of calcium and magnesium is called the softening of hard water.

How to Soften Hard Water

There are usually quite a number of calcium bicarbonate [$Ca(HCO_3)_2$] and magnesium bicarbonate [$Mg(HCO_3)_2$] in hard water and this kind of water is hazardous. First, it might form scales which sticks to walls of boilers. This is because, while heating, hard water forms unsoluble calcium carbonate and magnesium carbonate. Its chemical reactions are:

$$Ca(HCO_3)_2 \overset{\text{heating}}{=\!=\!=} CaCO_3\downarrow + H_2O + CO_2\uparrow$$

$$Mg(HCO_3)_2 \overset{\text{heating}}{=\!=\!=} MgCO_3\downarrow + H_2O + CO_2\uparrow$$

The formation of such scales not only prohibits heat conduction, consumed more fuel, and in some cases it might cause the boiler to explode because of the crack in scales which created partial overheat. The other disadvantage is hard water can react with sodium stearate ($C_{17}H_{35}COONa$) in soaps and produces calcium stearate, an unsoluble precipitation. Soap in such cases will lose its specified detergence.

There are quite a number of ways to soften hard water. The most commonly used processes are chemical soften process and ion exchange soften process.

A certain amount of chemicals are added to the water to turn the soluble calcium and magnesium salt to an unsoluble precipitation for the chemical softening method. For instance, when a certain amount of lime cream [$Ca(OH)_2$] and sodium carbonate (Na_2CO_3) is added to the water, the lime cream might change calcium bicarbonate to calcium carbonate precipitation; and sodium carbonate will turn the calcium sulphate ($CaSO_4$) and calcium chloride ($CaCl_2$) in water into calcium carbonate precipitation:

$$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2CaCO_3\downarrow 2H_2O$$

$$CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + Na_2SO_4$$

The so-called ion exchange process uses ion exchanger to soften hard water. Exchangers normally used are sodium alumo-silicate, sulphonating coal, other ion exchange resins etc. They themselves are unsoluble in water, but the metal ion (such as sodium ion) they possess, which is harmless to water, can be used to exchange the harmful calcium, magnesium ions in water thus achieving the purpose of removing calcium and magnesium salts. When hard water passes an apparatus containing ion exchanger, calcium and magnesium ion in the water will be attached on the ion exchanger and sodium ion will enter into the water, which flows as soft water.

A combined method of jointly using chemical and ion exchange processes is often adopted by some plants to treat hard water. Usually in such cases, chemical process is firstly used for preliminary softening, and ion exchange process will later be used for further softening.

All the abovementioned, no matter the purification of drinking water or the softening of hard water are measures adopted for preventing the pollution of water caused by nature. The pollution of water is even more serious with the development of modern industry and agriculture.

New Problem in Eliminating Water Pollution

Water pollution caused by modern industry and agriculture mainly comes from the poisonous effluences emitted from industrial production plants. In 1950, in a small town called

Minamata of Kumamoto county in Japan, some cats got mad and paralyzed, at the end they jumped into the sea "to commit suicide". In 1953, it happened again in the same place that some people suffered from lethargy, madness and death. Later, an investigation conducted by the University of Kumamoto found that, the reason causing such Minamata disease was of the waste water and slag which contains organic mercury discharged from a nitrogen fertilizer plant. Normally, most of the mercury entering into a human body can be excreted without accumulation. Mercury will turn to mercury methyl while encountering microbe in sludges from rivers. Mercury methyl will settle for a long time in the nerve center of human body if it is absorbed by human beings through drinking water or eating fish. It might seriously impair one's health even lead to death if a poisoning dose is reached. Besides mercury compound, poison in water from industries includes some metals compounds such as cadium, chromium, lead compounds, cyanides etc.

Another important reason causing water pollution which has to be taken care of, is the nutrition in water discharged by industries, agricultural units or families. For example, those abovementioned include phosphorates in detergents, chemical fertilizers such as nitrates being washed away from farmland, excrement and urine, organic matters in municipal sewage, waste from food products factories, dairies etc. Such rich effluent nutrition in water causes a great propagation of water organic matters and the growing of algae everywhere. This might lead to the death of fish and other aquatic animals owing to the great consumption of dissolved oxygen in water.

The pollution of petroleum on oceans and rivers is also serious with the rapid increase of petroleum consumption. Two bridges on Kaihoja River in U.S.A. were burned because of the heavy fire caused by oil pollution in 1969. It happened once that about ten thousand sea gulls died owing to an oil pollution near Alaska Gulf. The oil pollution on Lee River has caused the death of a great number of trouts.

Therefore, the pollution of modern production on air and water is a new task confronting us which has to be studied and solved urgently. How can we develop modern production and prevent environmental pollution both at the same time? It is indeed not easy to solve such a difficult problem in a short time. But, we are convinced that mankind possess inexhaustible wisdom and power, all difficult problems will be solved by them through exploring.